G. M. ELLIOTT LIBRARY
CINCINNATI BIBLE SEMINARY
2700 GLENWAY AVE.
P. O. BOX 043200
CINCINNATI, OHIO 45204-3200

OUTLINES OF HISTORICAL GEOLOGY

TEXTBOOK OF GEOLOGY

PUBLISHED BY

JOHN WILEY & SONS, INC.

PART I

Physical Geology. By the late L. V. Pirsson. Third Edition revised by William M. Agar, Assistant Professor of Geology, Columbia University; Alan M. Bateman, Professor of Economic Geology, Yale University; Carl O. Dunbar, Professor of Paleontology and Stratigraphy, and Curator of Invertebrate Paleontology, Yale University; Richard F. Flint, Assistant Professor of Geology, Yale University; Adolph Knopf, Professor of Physical Geology, Yale University; Chester R. Longwell, Professor of Geology, Yale University. Revision Edited by Chester R. Longwell. Cloth; 6 by 9; 488 pages; 322 figures.

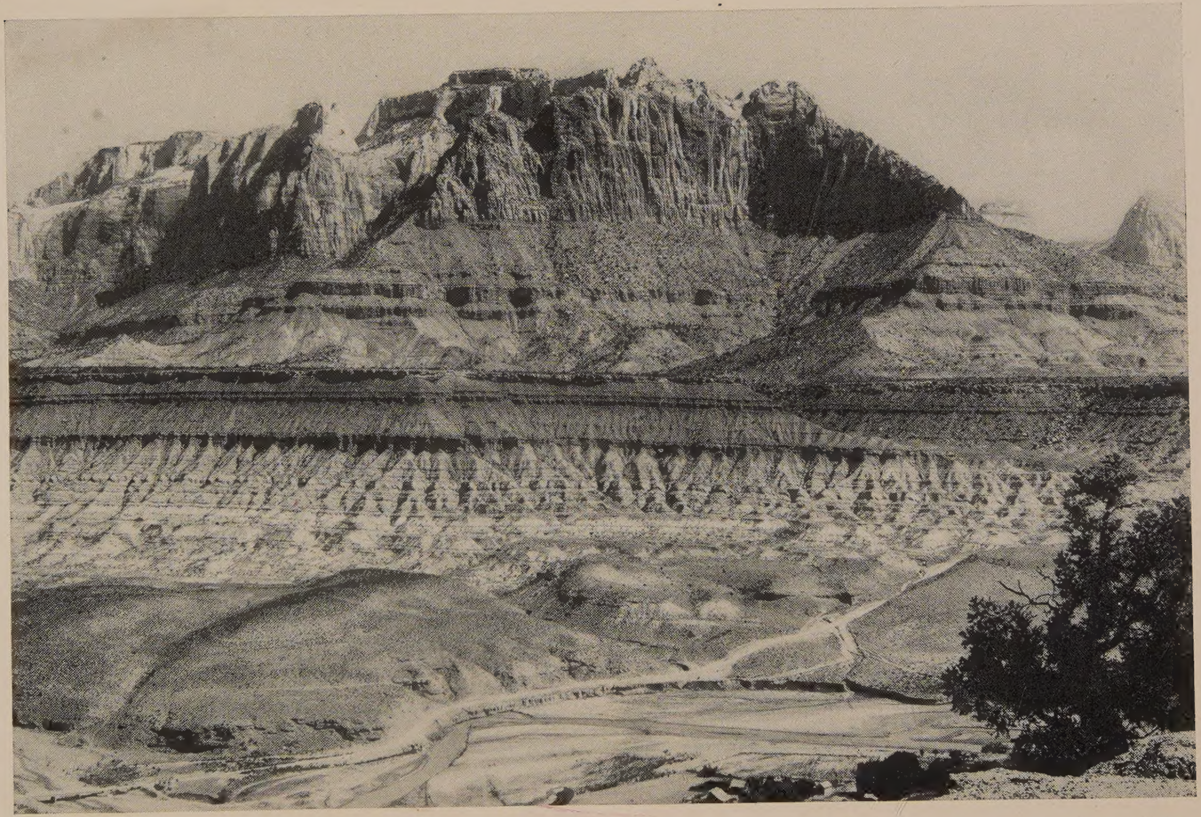
PART II

Historical Geology. By Charles Schuchert. Second Edition, Rewritten and Enlarged. Cloth; 6 by 9; 724 pages; 237 figures in text, 47 plates, and folding colored geological map of North America.

Outlines of Physical Geology. Prepared from the Third Edition of Part I of A Textbook of Geology by the late Louis V. Pirsson, and Charles Schuchert. By Chester R. Longwell, Professor of Geology in Yale University. Cloth; 6 by 9; 376 pages; 273 figures.

Outlines of Historical Geology. Second Edition, Rewritten. By Charles Schuchert. Cloth; 6 by 9; 348 pages; 157 figures.

Foundations of Geology. Being a Combination of Outlines of Physical Geology, and Outlines of Historical Geology.



West Temple of the Virgin, Zion National Park, Utah. A 4000-foot wall of red Triassic and Jurassic rocks, carved out of the Colorado Plateau by the Rio Virgin, and sculptured by subsequent erosion. Courtesy of the Union Pacific System.

OUTLINES OF HISTORICAL GEOLOGY

BY

CHARLES SCHUCHERT

Professor Emeritus of Paleontology in Yale University and of
Historical Geology in the Sheffield Scientific School

GEORGE MARK ELLIOTT LIBRARY
The Cincinnati Bible Seminary

SECOND EDITION, REWRITTEN

NEW YORK
JOHN WILEY & SONS, Inc.
London: CHAPMAN & HALL, Limited

Annex
560.9
S384o

Copyright, 1924, 1931,
by CHARLES SCHUCHERT

All Rights Reserved

This book or any part thereof must not be reproduced in any form without the written permission of the publisher.

Printed in U. S. A.

Printing	Composition and Plates	Binding
F. H. GILSON CO. BOSTON	TECHNICAL COMPOSITION CO. CAMBRIDGE	STANHOPE BINDERY BOSTON

PREFACE TO THE SECOND EDITION

When the first edition of this book appeared, in 1924, it was combined with Part I, Physical Geology, of the Pirsson-Schuchert Text-book to make a new book called "Introductory Geology." This shorter treatise was intended for institutions wherein the course in Geology was planned for civil and mining engineering students, or other professional students whose main interest would lie along the lines of Physical Geology, but who should have at least an outline of Historical Geology as well. Hence the portion dealing with the latter subject comprised less than a third of the entire volume, about 200 pages out of more than 600. In the present combination, however, the Physical Geology is condensed and the Historical Geology expanded, so that the two are of approximately equivalent lengths, with the idea that such a division will make a better balanced elementary course, and insure for Historical Geology the attention it deserves.

The framework of the new edition is necessarily much the same as in the earlier one, the changes being mainly along the line of rearrangement, or such as were needed to bring the work up to date. All of the discussion of the plants and animals, which is so essential to the understanding of Historical Geology, has been brought together in two chapters toward the front of the book; and emphasis has been laid more on the living animal than heretofore. With this "short course" in Zoölogy and Botany out of the way, it is believed that the continuity of the historical story will be less broken. More history of geologic thought has been introduced, and more stress has been laid on change and evolution as the keynote of all geologic chronology and of paleontology. The chapter on paleogeography has been considerably lengthened, as have those on the Cenozoic and on the mammals. All of the paleogeographic maps have been redrawn in accordance with the latest evidence available.

In the preparation of the book I have been greatly aided by my colleagues. Professor Carl O. Dunbar, who teaches Historical Geology at Yale University, has read the entire manuscript and the proof as well, and his many suggestions have been adopted. All of the galley proof was also read by Professor Chester R. Longwell, and certain parts of it by Professor Adolph Knopf. The book is the better for the criticisms of these men who are actively engaged in teaching Geology, and I am thankful to them. I also owe a debt to Doctor W. H. Collins, Director of the Geological Survey of Canada, who kindly gave me the benefit of his wide knowledge in the Pre-Cambrian chapters.

New illustrations have come from a variety of sources, which are further credited in the text. I should mention, however, for special courtesies in this matter, the United States Geological Survey, Professor Henry Fairfield Osborn and the American Museum of Natural History, the New York State Museum at Albany, the Field Museum of Natural History at Chicago, and the Princeton University Press. Mr. S. E. Norris of John Wiley and Sons has, in his kindly way, supervised the making of the printing blocks.

As in all my earlier text-books, the burden of editing the manuscript and seeing it through the press has fallen upon my secretary, Miss Clara Mae LeVene, whose aid is again thankfully acknowledged. The new drawings are the work of Miss Lisbeth Krause of Yale University, and Mr. O. W. Goodloe of the United States Geological Survey, for whose coöperation I am grateful.

CHARLES SCHUCHERT

PEABODY MUSEUM OF NATURAL HISTORY,
YALE UNIVERSITY, NEW HAVEN, CONN.,
August, 1930.

TABLE OF CONTENTS

PART II. — OUTLINES OF HISTORICAL GEOLOGY

CHAPTER PAGE
I. Historical Geology 3
II. The Rock Record as Summarized in the Geologic Time-table 6
III. Fossils, the Records of Ancient Life 16
IV. Evolution, the Constant Change of Living Things 27
V. An Introduction to Plants and Animals. I. Plants 34
VI. An Introduction to Plants and Animals. II. Animals 46
VII. The Earth Before Geologic Time 66
VIII. The Dawning of Earth History: The Archeozoic Era, Age of Marine Larval Life 74
IX. The Proterozoic Era: Age of Primitive Marine Life 87
X. Paleogeography: The Procession of Ancient Geographies . . . 101
XI. Early Paleozoic Time: The Age of Marine Invertebrates . . 119
XII. Middle Paleozoic Time: The Age of Fishes 139
XIII. Late Paleozoic Time: The Age of Amphibians and Coal-making Plants 157
XIV. Permian Time: The Transition from Paleozoic to Mesozoic . . 173
XV. Early Mesozoic Time 190
XVI. Land Reptiles and Toothed Birds of Medieval Time 214
XVII. Late Mesozoic Time 226
XVIII. The Dawn of the Recent in Cenozoic Time: Age of Mammals 244
XIX. The Evolution of Mammals and the Rise of Mentality 267
XX. Pleistocene Time and the Last Glacial Climate 292
XXI. Man's Place in Nature 307

Collateral Reading 324
Index 329

PART II

OUTLINES OF HISTORICAL GEOLOGY

BY

CHARLES SCHUCHERT

OUTLINES OF HISTORICAL GEOLOGY

CHAPTER I

HISTORICAL GEOLOGY

"To him who commands time nothing is impossible."

HESIOD.

Physical Geology, as we have learned in the first part of this book, deals with the architecture of the outer shell of the Earth, and with the geological processes which have operated to bring it about. Historical Geology, on the other hand, studies the results achieved by these forces during the past geologic ages, presenting in chronologic order the procession of important events, physical and vital, that the Earth is known to have gone through. It carries the history of the Earth back of the human record, through a thousand million years whose only annals are written in the rocks and in the life of the past which they contain. This geologic history is, however, but an imperfect chronicle, abounding in omissions or alterations of record, due to erosion or deformation or metamorphism. Probably not even all the grander features, such as the times of mountain making or of recurrent oceanic spreading, are yet known, and relatively little regarding the detail of the formations and faunas, despite a century or more of study by geologists and paleontologists in all lands.

The keynote of all geologic history, whether of physical events or of life, is *change*. On the physical side, the Earth has, we believe, progressed from a hot molten state to one with a more or less solid and cold crust. Accordingly, as the Earth cooled and began to encrust itself, the very thick gaseous envelope began to evolve into a thinner one, more like that of the present. In other words, the water vapor condensed into rain and fell upon the hot crust, rose as steam over and over again, and finally came to lie in the depressions and to fill the ocean basins. Geologic time, properly speaking, began when the Earth had a cold exterior, and when the rain and wind commenced their ages-long task of wearing down the high places and transporting them into the low ones. The lands are altering slowly but continually, due not only to the work of these atmospheric agencies but probably to adjustments made necessary by the shrinking of the Earth's interior.

In recent years, many geologists have lost faith in the old dogma that the Earth is a shrinking mass, and it may well be that crustal shortening alone could not explain the making of the many mountain systems that have arisen throughout geologic time. Most geologists, however, still believe that the Earth is a shrinking mass. On the other hand, the crustal shortening demonstrated in every mountain chain appears to indicate that there may also have been some continental drifting; in other words, that the continents, not so much as a whole as in parts, have shifted horizontally, but surely never to the extent or in the manner postulated by the recently proposed Wegener theory (see p. 335 of Part I).

The oceans have always been where we see them now, but they appear to have periodically grown larger and deeper, while the continents have lost parts of their marginal areas and have attained from time to time higher average levels. When the oceanic basins subside, it follows that the continents must stand higher above sea-level, though they have not risen at all. The added gravity and the resulting greater pressure then cause them to flatten down through continental creep. Through crustal movements and continental creep the oceans are permitted to spread periodically over the continents as shallow seas, and they are made to spill more widely through the added land wash that the rivers dump into them. The floods are as often withdrawn by the periodical deepening of the oceans but *there never has been general interchange in position between the continents and the basins of the oceans.* Nor were the continents ever amalgamated into one — a Pangea that has since broken apart and allowed them to drift into their present positions.

Great and grand ranges of mountains have been raised many times near the borders of the continents or elsewhere, only to be degraded little by little and spread out as sheets of sediment over the bottoms of the adjacent seas. "Rocks fall to dust and mountains melt away." Originally the continents were vastly larger and trended east and west; now they strike north and south, due to founderings of their margins and of former connecting lands into the depths of the oceans. The oceanic basins, in other words, have grown steadily larger at the expense of the original lands.

Just as the surface of the Earth is in a continual state of slow change, so in consequence must be the atmosphere, since it results from the Earth's exhalations. When the lands are moving and rising into mountains, igneous activity is greatest, and deep-seated rock materials are injected into the Earth's crust, lavas and volcanic ashes are spread over it, and new water vapor and gases are added to the atmosphere.

All this crustal and atmospheric instability results in changing environments for the plants and animals, in greatest degree among the organisms of the lands, and least so in the oceanic realms. Life, beginning probably in the seas, at some early time when they first became fit for its habitation, developed into an astonishingly great variety of marine invertebrates, and out of one of these stocks came the little lancelet, " the prophecy of a fish." Spreading up the rivers, these lancelets doubtless developed into the fresh-water fishes, which are present early in the fossil record. Rivers in arid regions, however, are treacherous abodes for life, since they are dependent upon rains and humid climates, hence in places the fishes found their water homes recurrently drying up around them, and some were ultimately forced out upon the lands, there to start the long upward evolution toward the higher air-breathing vertebrates. This evolution has not, however, been a steady upward process, but through ceaseless trial and failure and the consequent weeding out of the less fit, there have arisen ever more perfected organisms, with greater and greater mentality, to culminate finally in man.

CHAPTER II

THE ROCK RECORD AS SUMMARIZED IN THE GEOLOGIC TIME-TABLE

The rocks of the Earth's crust contain the record of their own history, which man has spent some centuries in learning to read. A rock, say, is made of sand grains cemented together — it is a sandstone; the beds in which it occurs are evenly layered or stratified, hence it was laid down by water; it has remains of marine animals in it, therefore it was formed beneath the sea; it is coarse-grained, with pebbles and boulders, so it was deposited not far from a shoreline; it is part of a very thick group of rocks, or formation, hence there must have been highlands not far away to supply this great amount of material, after it had been worn to fragments by erosion. These were the details that geologists learned as they studied rocks in the field and in the laboratory. But before these details could be put together to make a connected story, keys had to be found to make their broader meaning clear. These keys are the principles that underlie Historical Geology.

The first of these principles, already discussed in Part I, is that rock formations succeed each other in a certain definite order, so that, unless the sequence has been overturned by some disturbance in the crust, the youngest rocks are at the top and the oldest at the bottom. This *law of superposition*, as it is called, was already seen and noted by Lehmann and Füchsel, two German geologists, in the latter half of the eighteenth century.*

Stressed also in Part I (pp. 288–291) is the idea that when the rocks of two formations lie in different attitudes with respect to each other, *i.e.*, are unconformable, something happened after the deposition of the lower formation was completed and before that of the upper one was begun, of which the record is absent; in other words, there is a " lost interval " at this point, representing either a time when the sea was absent from the region in question and consequently no rocks were laid down, or a time of erosion on land, when rocks that had been deposited there were completely worn away. This is the *law of unconformability.*

A third principle, formulated by a Scotch geologist, James Hutton, also toward the end of the eighteenth century, is that of *uniformitarianism*, which holds that the natural forces that affect the Earth — rain and wind, atmospheric decay, etc. — have always operated as we see them at work now, but with varying strength; in other words, " the key to the past lies in the present."

---

* For the history of Geology, see the list of collateral reading which follows the last chapter in the book.

A fourth principle is that the geologic age of a formation can be determined by the fossil animals or plants it contains. This idea was worked out over a number of years by an English surveyor, William (" Strata ") Smith (1769–1839), who began to note the recurrence of familiar strata, marked by the same organic remains, as he travelled to and fro over the country in his professional work. By 1801 Smith had drawn up a " card of British strata," showing how, by this method, rocks in widely different places could be proved to be of the same age. He had no time to publish his ideas, but a friend of his copied the card and sent it to other geologists, both in England and on the continent, with the result that, confirmed within a few years by work around Paris, the principle thus established became the very foundation stone in the interpretation of stratified rocks. This *principle of organic correlation* is the most important one in Historical Geology.

A fifth principle is concerned with the dating of igneous rocks when these well up from the Earth's interior into the rocks of the crust. As now exposed, these solidified intrusive magmas occur as more or less large batholiths of granite-like crystalline rocks, and as volcanic necks, dikes, sills, etc., described in Part I, pp. 240–246. Inasmuch as their upwelling and intrusion are necessarily subsequent to the making of the rocks which they traverse or into which they enter, an intrusive rock (not an extrusive lava flow) is always younger in age than any rock which it cuts. This is the *principle of intrusion.*

With these principles to guide them, geologists began to see that each rock formation was to be studied, not for itself alone, but with a view to determining its definite place in the history of the Earth. As more and more formations were studied, in one country after another, the story grew and grew, until it is now in a fair way toward completion, though details are wanting in most places. The farther one goes back, naturally the more obscure the history becomes, and it seems probable that much of the early part of it can never be retrieved.

To express this history in a summary fashion, geologists have invented a chronological table, known as the geologic column or geologic time-table, which is now to occupy our attention. *It is the A, B, C of Historical Geology, and must be learned before further progress can be made.*

GEOLOGIC CHRONOLOGY OF NORTH AMERICA

ERAS DURATION,%	SUBERAS	PERIODS AND EPOCHS		ADVANCES IN LIFE, AND GLACIAL TIMES	OROGENIC TIMES	AGES	
Psychozoic or Recent Era				Time of mental dominance		Age of Reason	
						PLANTS	ANIMALS
CENOZOIC OR MODERN ERA, 4%	Late Cenozoic, 2%−	Neogenic	Pleistocene or Glacial	Periodic glaciations Dawn of social life and industry among men Extinction of large mammals	Cascadian Revolution	Age of Modern Seed Floras (*Angiosperms*)	Age of Man
			Pliocene	Cooling of climate Man ape changing into man			Age of Mammals
			Miocene	Culmination of mammals and land floras	Disturbance		
	Early Cenozoic, 2%+	Eogenic	Oligocene	Rise of anthropoids Last of archaic mammals			
			Eocene	Spread of placental mammals Dawn of modern life Rise of grasses, cereals, and fruits			
MESOZOIC OR MEDIEVAL ERA, 8%	Late Mesozoic, 4%−	Upper Cretaceous 3%−		Glaciation in Australia Last of ammonites Extinction of dinosaurs, pterodactyls, and toothed birds Rise of archaic mammals and birds	Laramide Revolution		Age of Reptiles and Ammonites
		Lower Cretaceous 1%+		Spread of flowering plants and modern insects	Disturbance	Age of Medieval Seed Floras (con.) (*Gymnosperms*)	
	Early Mesozoic, 4%−	Jurassic 2%−		Rise of toothed birds and spread of pterodactyls Spread of primitive mammals Culmination of ammonites	Nevadian Rev.		
		Triassic or Tyrolian 2%−		Rise of dinosaurs, pterodactyls, and reptilian mammals Spread of cycads and conifers	Palisade Dist.		

GEOLOGIC CHRONOLOGY OF NORTH AMERICA *(continued)*

ERAS DURATION %	SUBERAS	PERIODS		ADVANCES IN LIFE, AND GLACIAL TIMES	OROGENIC TIMES	AGES	
						PLANTS	ANIMALS
PALEOZOIC OR ANCIENT ERA 24%+	Late Paleozoic, 8%-	Permian 3%-		Last of trilobites and Paleozoic corals Periodic glaciations in southern hemisphere Spread of reptiles and rise of seed floras	Appalachian Rev.	Age of Medieval Seed Floras	Age of Amphibians
		Carboniferous	Pennsylvanian 3%	Dominance of spore floras. Coal making Spread of primitive insects and amphibians	Repeated orogeny	Age of Spore-bearing Floras	
			Mississippian 2%-	Spread of ancient sharks and culmination of crinoids	Disturbance		
	Middle Paleozoic, 5%-	Devonian 3%-		Rise of amphibians, marine fishes, and primitive ammonites First forests and spiders	Acadian Dist.		Age of Fishes
		Silurian 2%-		Rise of air-breathing land animals (scorpions) Spread of Paleozoic reef-corals First known land plants		Age of Marine Floras	
	Early Paleozoic, 11%+	Ordovician 4%		Rise of freshwater fishes and of corals Spread of molluscs Culmination of trilobites	Taconian Dist.		Age of Marine Invertebrates
		Cambrian 7%-		Rise of shell-bearing molluscs Dominance of trilobites First well-known marine faunas	Disturbance		
PROTEROZOIC ERA of primitive marine life, 32 % An early and a late glacial period For detail see table in Chapter IX					Killarney-Grand Can.		
ARCHEOZOIC ERA of oldest known life, 32 % Geologic history very obscure For detail see table in Chapter VIII					Laurentian-Algoman		Age of Larval Life

Framework of the Geologic Time-Table

Revolutions. — Chronological tables are an inevitable accompaniment to historical studies, and Historical Geology is no exception. In this case, however, we are dealing not with actual dates as in human chronologies, but with vast lengths of time that can be expressed only in rough estimates. Moreover, the geologic time-table has a two-fold nature, in that it must express at once a sequence of rocks and a sequence of time. Nevertheless, it is possible to point out in Earth history, just as in human history, certain great events, on either side of which there is, so to speak, a different world. In Geology, these outstanding events — if anything that takes millions of years to accomplish can be called an event — are very widespread crustal disturbances, expressed in the making of great mountain systems. These great crustal deformations in the history of the Earth are called *revolutions.* A glance at the time-table will show that geologists have so far determined six of them. The five major ones are, beginning with the oldest, the Laurentian-Algoman, the Killarney-Grand Canyon, the Appalachian (late Paleozoic), the Laramide (late Mesozoic), and the Cascadian (late Cenozoic). A sixth one, the Nevadian, of somewhat less import, took place at the end of the Jurassic period.

These times of vast mountain making not only change the physical aspect of the Earth's surface, but have a great effect on the life of the time throughout the world; when these revolutions occur, the plants and animals find themselves facing a new environment — dry where it has been wet, cold where it has been warm, high where it has been low — and they must adapt themselves to the new conditions or perish. Such times are therefore spoken of as "critical periods." The underlying cause for them is marked crustal unrest, expressed in continental elevation, in the making of mountains in many continents, and in the deepening of the oceans, the whole resulting in vastly altered climates.

Mountain making, as we saw in Part I, whether world-wide or restricted to a single continent or a part of a continent, starts afresh the cycle of erosion, and the atmospheric forces at once set to work to destroy what has been made. When mountains are being thus worn down, the rock record is destroyed rather than preserved and so, along with the revolution, goes a very long time of erosion with consequent loss of record, which is called an erosion *interval.*

Eras. — Between these great revolutions and intervals, which mark great changes both in the rock record and in the life record, are the *eras,* the longest divisions of time used in Geology — the volumes in the book of geologic time. The names of the eras are taken from the Greek and are based on the state of advance (= evolution) reached by the animals and plants: Archeozoic (primitive life), Proterozoic (early life), Paleozoic (ancient life), Mesozoic (medieval life), and Cenozoic (modern life). We are now living in the Psychozoic era, the Age of Reason, which has but recently begun, geologically speaking.

Periods and Systems. — A geologic era is composed of a group of *periods* (time) represented by *systems* of rocks, the chapters in the geologic volumes. As yet, however, it is not possible to give a short and clear definition of the physical and organic characteristics that distinguish periods, and the following general statement must suffice. Each period, as now defined, embraces one to three variously large and oscillating invasions of the lands by the oceans. Each of these marine invasions is characterized by three phases of sea extent: (1) an early stage with smaller seas; (2) a middle stage, when the transgressing flood is at its greatest; and (3) a retreating stage, when the continent becomes more and more emergent. These phases are known to geologists as *epochs* of time and are represented by *series* of rocks. The periods begin and close with the smallest inundations or phases of recording, while the maximum of flooding occurs during their middle phase. Finally, the periods or systems may close with local or relatively widespread mountain making (= orogenic), or geographically extensive horizontal elevation (= epeirogenic), either sort causing what is known as a *disturbance.* (See also p. 115.)

The names of the periods, and of the series as well, are generally taken from the regions in which the strata were first studied, even though the record may there be incomplete. Thus the term Silurian period or system is taken from that part of England where the ancient tribe of Silures lived, and where the rock sequence is practically complete, while the Devonian period or system is named from Devonshire, where, however, the sequence is so complicated by subsequent mountain making and volcanic materials that its history had to be determined from the wonderful development in the Rhineland of Germany.

Formations (see also pp. 201–202 of Part I). — Just as in Biology the species is the unit of classification, so in Geology the primal unit is the *formation*; the formations are the paragraphs in the geologic chapters. In one place a formation may be but a few feet thick and in another 1000 feet or more, and the lesser thicknesses may be due either to incompleteness of deposition, removal of record through erosion, or a slower rate of deposition.

A formation may embrace a single more or less thick succession of like sediments, such as the Trenton limestone, or a succession or alternation of sediments that are unlike but have closely related faunas, such as the Hamilton formation. In short, any set of conformable strata that are without significant time breaks and are naturally grouped together because of certain stratigraphic or faunal reasons may be termed a formation.

Breaks. — Other time intervals which do not generally appear in the geologic column, but which are nevertheless of great significance, are the erosion intervals, or *breaks*, the " lost intervals " in the succession of strata, when no local record was being made. Such times of lost record are known to be many, and the further growth of the column will come through the discovery of formation after formation along the lines of these breaks. Many of these records, however, are forever buried beneath younger formations or the waters of the oceans.

The breaks between the periods or systems, when the seas generally are completely off the continents and the latter are undergoing erosion, are usually of much longer duration than are the disconformities between the formations.

The breaks or nonconformities are not only indicated by the lay of the rocks themselves, but even better and with more certainty by the entombed fossils. The longer the time interval of non-recording, the greater are the differences between the superposed fossils. When these great differences were first observed, geologists were astonished, and to explain them there arose the theory of catastrophisms and re-creations.

This theory, which was brought into general acceptance by the great French paleontologist, Cuvier (1769–1832), held that in the past the entire world had undergone catastrophes which destroyed all the organisms. These were followed by long times of crustal stability, during which faunas more advanced than the previous ones were created. In Cuvier's time, however, the geologic sequence was poorly known, and his catastrophisms are now interpreted as the " breaks " in the geologic sequence, representing losses of record due to mountain making or other causes. Since then, the strata that fill in these breaks have in the main been discovered elsewhere, and these often have the transition animals unknown in Cuvier's time.

How Old is the Earth?

For thousands of years man has been asking this question, but measurement of the duration of geologic time became a scientific possibility only during the past century. Among the ancient priesthood of Egypt and Chaldea the idea that the Earth was old, very old indeed, was widespread, nevertheless the western Europeans were contented until the last century to hold with Bishop Ussher, primate of Ireland, who declared in 1650 that the world was made in the year 4004 B.C.

Long before Geology attained a firm foundation, it was seen by philosophers that the Earth might reveal its own age. Hutton, the prophetic geologist, said late in the eighteenth century: "I see no vestige of a beginning — no prospect of an end," meaning that geologic time was very, very long. The Greek historian Herodotus (484–424 B.C.) saw in sediments a means for determining something regarding the length of human prehistory. Hearing of the claims of the priesthood, he lived some years in Egypt, where he saw the annual floods of the Nile spread layer upon layer of silt over its valley, and in them beheld the possibility of testing these claims. He saw, in other words, that lower Egypt is truly "the gift of the Nile," and concluded that the delta must have taken many thousands of years to form through the annual additions of the river muds.

According to Lane, there are about forty ways of estimating the age of Mother Earth. These methods, arranged in four groups, are as follows: (1) By the rate of loss of heat in Sun or Earth. Here, however, the data are largely hypothetic and the results are now known to be very unreliable. (2) By the rates of erosion of the rocks, and (3) by the rates of their accumulation when re-deposited as sediments and salts. The rates of erosion have, however, varied greatly in the past; hence results by this method are subject to great error. (4) By rates of atomic disintegration. This, the *radioactive method*, is the most reliable one.

The present rate of land erosion divided into the total thickness of the stratified rocks of the crust — all these are the result of erosion plus considerable volcanic ash or dust — gives one geologic answer to our question. The rate of land erosion is obtained by measuring, near the mouth of a large river, the load of sediment it transports annually and deposits upon its delta, along with the amount of mineral matter it holds in solution. Or, we may divide the estimated amount of salts in the ocean by the annual amount delivered by the rivers. Learning has shown, however, that the annual rates of land erosion, and the salinity of rivers, must have differed greatly in the past, since to-day the lands stand on the average higher than they usually did in geologic time, hence erosion is more rapid and rivers are more salty, whereas during long geologic stretches the land was reduced to a plain that stood but little above sea-level, and erosion was very slight. By these very imperfect methods, the age of the Earth was once placed at 38 to 96 million years, and twenty-five years ago geologists quite generally accepted 100 million years as the probable length of time since the beginning of the Archeozoic era.

The physicists have also had their methods for determining the probable age of the Earth. Lord Kelvin struck consternation into the geologists by his announcement, more than half a century ago, that not more than 40 million years could have elapsed since the solidification of the Earth from its molten condition. Then came the epochal discovery of radium in 1898, and the knowledge that this element breaks up at a definite rate that is measurable, so that the age of radium-bearing rocks can be calculated. Shortly thereafter the physicists told the geologists that they must multiply their figures by at least ten, and later by about sixteen! However, the method seems to withstand the force of destructive criticism, and Earth students will have to fit their knowledge into its calculations.

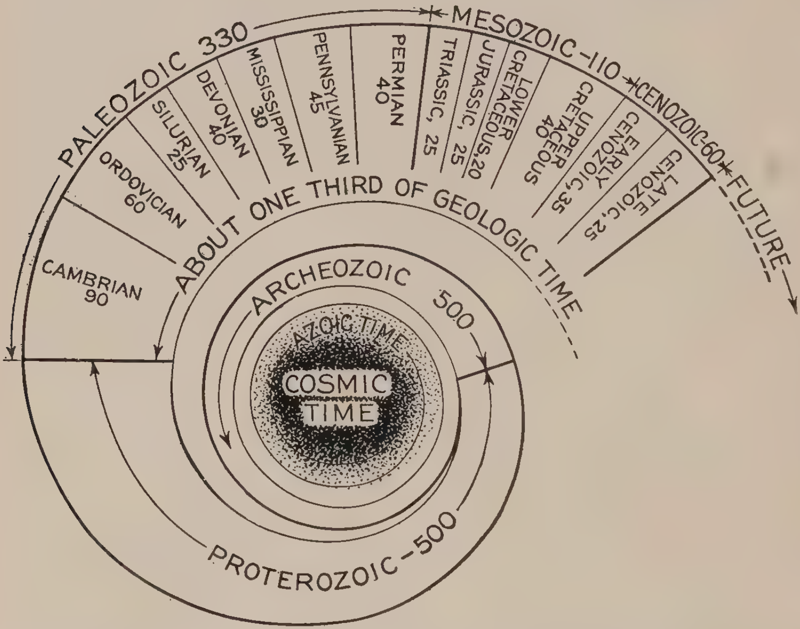


Fig. 1. — The duration of geologic time illustrated by a spiral graph, on the basis of about two billion years. All numbers in million years. Modified after David White, 1928.

A recent attempt by the writer to find out if the known geologic facts could be reconciled to this total deduced by the physicists resulted as follows: The total thickness of known stratified rocks, beginning with the Paleozoic, in North America reaches the sum of 308,000 feet (58 miles); when the major breaks (losses of record) shall have been eliminated in coming years by the finding of new formations, this maximum will certainly be around 400,000 feet. This figure, divided into the age total on the basis of radioactive minerals (540 million years since the beginning of the Paleozoic), gives an annual rate of deposition considerably in excess of that previously postulated, *i.e.*, for the Cenozoic, 1 foot in 730 years; for the Mesozoic, 1 foot in 1400 years; for the Paleozoic, 1 foot in 2690 years. Hence if the rate during long stretches of geologic time has been even slower than this, which is probable, the amount of sedimentary deposits and the amount of time figured on the basis of radioactivity are not irreconcilably far apart.

Accepting 1500 million years for the duration of geologic time, the radioactive minerals indicate that Cenozoic time endured for 60 million years, Mesozoic for 110 million, and Paleozoic for 330 million, giving the ratio 1 : 2 : 5. Less well determined calculations give for the Proterozoic 500 million years, and the Archeozoic may have lasted at least that long. Back of geologic time lies the Cosmic eon, to which astronomers ascribe a possible length of 500 million years. Accordingly we may say that on the basis of astronomic data the Earth seems to have had its origin out of the Sun 2 billion years ago; and that the radioactive data from Earth-derived minerals appear to show that our mundane sphere had a solid crust 1500 and perhaps 1800 million years ago.

On the basis of these figures, the age of the Earth is shown in the spiral graph on page 14 (Fig. 1).

CHAPTER III

FOSSILS, THE RECORDS OF ANCIENT LIFE

> "The earth is a vast cemetery where the rocks are tombstones on which the buried dead have written their own epitaphs."
>
> Louis Agassiz.

On the land, we see life all about us: plants in the form of grass, herbs, and trees; worms, insects, snails, frogs and snakes, birds, cows, and horses, which collectively we know as animals. The waters of the lands are also replete with plants and animals; in the rivers and lakes we find not only a variety of fishes and amphibians, but also crayfishes and snail shells. The shallow sunlit waters of the oceans are especially rich in plants (seaweeds) and in animals of all sizes in such untold numbers and such strange and manifold variety as to be beyond the belief of one who has never looked into the salt waters with an inquisitive mind.

Such a vast abundance of life as we see now has probably been present in the oceans and on the lands for untold millions of years, but the only way in which we can learn what the ancient life was like is by its becoming, as we say, *fossilized.*

What Fossils Are. — The term fossil comes from the Latin word *fossilis*, which means something dug out of the earth. Nearly all the ancient peoples, however, applied the term both to minerals and to stones having lifelike forms, regarding as fossils such things as trilobites or " three-lobed stones " (see p. 59), ammonites, " stones curved like Ammon's horns " (see p. 212), along with calcite or " lime stone." By the geologist, however, the term fossil is restricted as a rule to the remains, in the rocks, of organisms that have lived in the geologic past; and the bedded rocks that contain them are therefore their graveyards.

Wherever Nature or man erodes or digs into Mother Earth there may be a revelation, not only of the things that once lived and loved but also of the links that bind ancestral history to our own. This find may be but a fragment of what was once a perfect living plant or animal, perhaps only the imprint of a leaf or a footstep in the mud, the valve of an oyster or pearl shell, a single tooth or bone of a fish or mammal. On the other hand, it may be a complete mammoth carcass frozen in the tundras — a genuine case of cold storage that is now probably some tens of thousands of years old. Nevertheless the less thrilling shells may have the grander story to tell, of a time hundreds of millions of years ago.

In view of the imperfection of the geological record, the surprising thing is that it tells so much, and the finding of fossils may be more significant than the discovery of ancient human civilizations. In breaking rocks for fossils or finding them loose in the soil where they have been weathered out by Nature, one is repeatedly thrilled at getting some significant or beautifully preserved specimen that no human eye has seen before, and all the more so when one keeps in mind its long burial, which may be anywhere up to 500 million years.

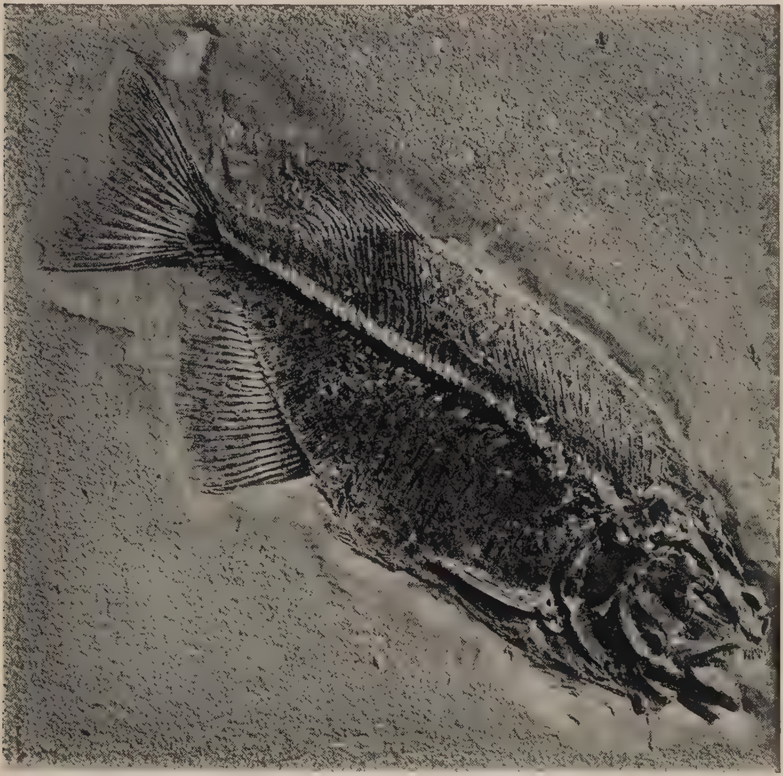


FIG. 2. — Skeletal remains of an Eocene fresh-water fish, clearly preserved on a slab of Green River limestone from Wyoming. Peabody Museum, Yale University.

How Fossils are Preserved. — The first necessity for preserval is burial, alive or soon after death. Burial prevents the organism from being eaten by scavenging animals, and from chemical destruction by the atmosphere in the case of land life or by the water for those organisms that live in the rivers or the lakes or the sea. Once the organism dies, it is quickly attacked by the invisible but omnipresent decomposing fungi and bacteria, and soon all the soft parts and later the tougher ones vanish, leaving only the hard portions such as skeleton or shell. This process also goes on in the life that is buried, but here the decomposition takes place much more slowly.

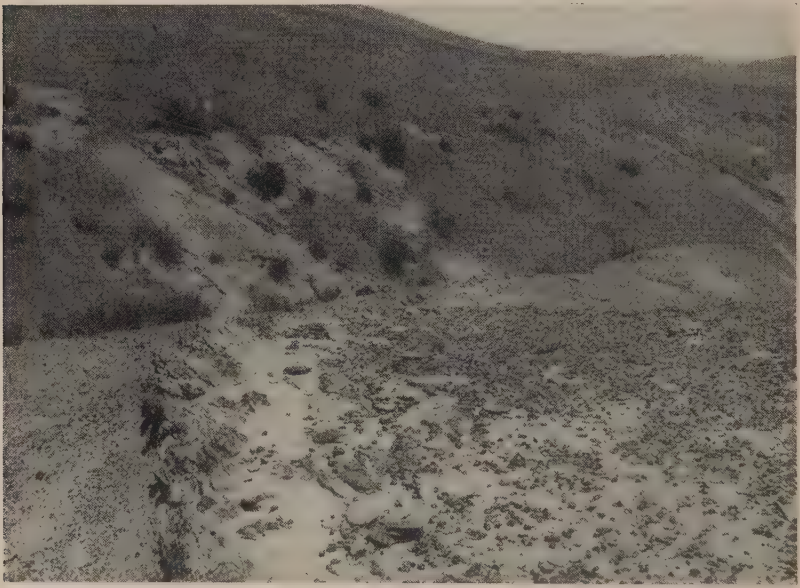


Fig. 3. — Fossils as they occur in the field. The circular echinids known as sand dollars (*Echinarachnius*) weathering out of Miocene sandstone in King's County, California. At the left, they are weathering out of a low ridge that dips to the right at an angle of about 45°. Photograph by Ralph Arnold.

The accident of complete burial may thus make an imprint or save the hard parts of an organism, but even the remains so covered may be dissolved away by the percolating waters within the rocks; in addition, the muds and sands undergo compacting, cementation, and slight movement, all of which tends to destroy the imprints and the delicate and small individuals. Accordingly, complete destruction is the rule for all soft-bodied creatures such as the jellyfishes; and even where there is a shell or skeleton, preservation depends upon the chemical nature of these structures, upon immediate burial, upon the nature of the enclosing sediments, and later upon the chemical content of the waters in the rocks. In other words, all but the smallest fraction of the multitude of animals and plants vanish into the elemental materials whence they came. Probably far more than 99 per cent of all individuals have thus been destroyed.

The chances for survival as fossils are naturally greatest among the life in the seas and oceans, since land plants and animals must as a rule be transported by fresh waters to some area of burial. The fossils most commonly met with are those of the shallow seas, a fact which shows at once that these are the areas where burial takes place most easily. In fact, many animals live buried in, or burrow around in, the muds and sands of the sea bottoms, and when dead are thus naturally entombed. It is into these shallow seas that most of the eroded materials of the lands are washed, nevertheless the annual depth of silts and muds deposited in them is so slight that by this means alone no life could be buried quickly enough to keep it from destruction. What ensures quick burial is the fact that these seas are also the areas in which the tidal and other currents and the lifting and rolling of the surface waves impinge upon the bottoms where, especially in times of storms, they churn up the soft unconsolidated muds and leave the suspended

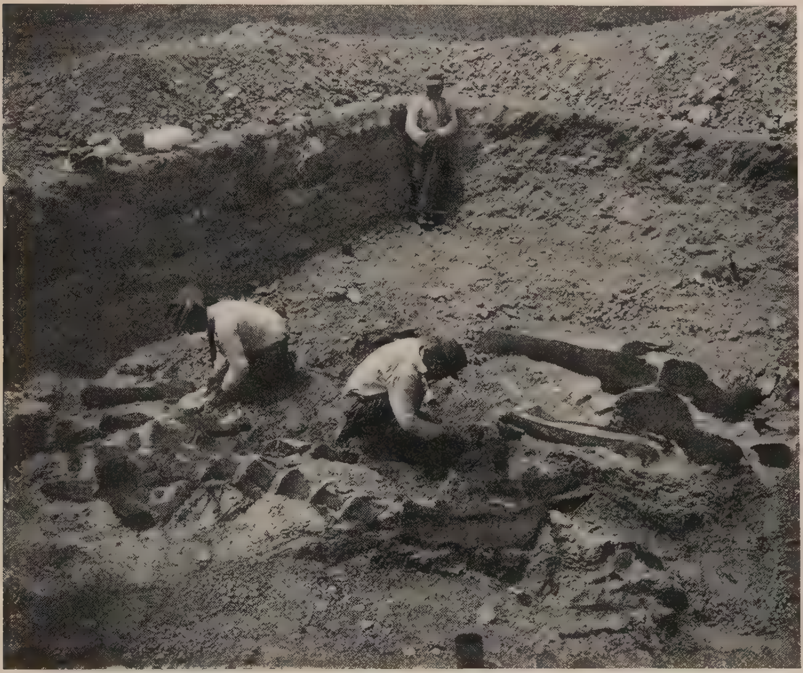


Fig. 4. — Fossils as they occur in the field. Bones of the ponderous dinosaur, *Brontosaurus*, in process of excavation in the Bone Cabin quarry of Wyoming. American Museum of Natural History.

sediment to settle down later on the life of the bottoms, smothering and entombing most of it. The mariners and fisherfolk of the Gulf of Mexico tell us of the milky waters to be seen here after storms have raised the white limy bottom muds into suspension.

Fossils are to be looked for especially, therefore, in evenly bedded strata of marine origin, particularly the more or less calcareous kinds, since the presence of lime helps to preserve the hard parts of animals, which are so largely of calcium carbonate or phosphate; and least of all in the red shales and sandstones, because the red color in most sediments is indicative of aërial oxidation, which removes the carbonaceous material of life and leaves the iron in the hydrated form to color the muds and sands.

On the lands, the shallow lakes, marshes, and bogs are the next best places for the preserval of life, and especially of the plants living in and about them. The acidity of the swamp waters is often such that but few of the decomposing fungi and bacteria are present; accordingly plants are preserved here in such quantities as to make peat bogs, the first stage in the formation of coal beds. As a rule not many animals live in such waters and yet at times thick beds of shell marls occur; while the animals of the lands or of the streams that flow into these lakes and bogs often find permanent burial here, and insects are blown or fall into them and so attain preservation. In this way large parts of land floras and insect faunas, along with fishes and an occasional bird feather or skeleton, are buried, as in Lake Florissant of central Colorado, into which fell repeatedly, in Miocene time, great showers of volcanic ash from nearby eruptions.

Such " rains " of volcanic ash are frequent causes of accidental burial of land life, making deposits many feet in depth, which suffocate and bury all plants and animals over wide areas. Further instances of such catastrophes are the erect tree trunks still standing in superposed forests in Yellowstone Park (Fig. 124) or the many fine mammal skeletons in the John Day formation of Oregon and elsewhere (Fig. 5). Volcanic ash beds are also very common on the bottom of the Pacific Ocean, and explosive volcanoes of the lands throw much ash into shallow seas, as is the case with Vesuvius and Etna.

In the deserts and along the seashores, wind-blown sands — " marching dunes " — bury much life, and in this way has come to us an occasional " mummy," such as the large duckbill dinosaur found in Wyoming, or the nests of dinosaur eggs from the Gobi desert of Mongolia. In the tundras, or frozen ground, of such countries as Siberia and Alaska, mammoth and rhinoceros carcasses have been frozen and so preserved in their entirety — skin, flesh, hair, entrails, stomach contents, and all (Fig. 145). Petroleum in the rocks also acts as a preservative, and "fossil" rhinoceros carcasses have come to light in the oil fields of Poland. Large animals are frequently mired in bogs or in quicksands, in shallow water or in the "dry streams" of semiarid regions, and thus preserved. Finally, in places petroleum springs evaporate into pitch pools, and after rains water lies on top of such treacherous places; lured by its appearance, the mammals come to drink, only to be mired in the sticky stuff; the cries of the unfortunates in turn bring on the carnivores and the carrion birds and all are at length engulfed to make the most instructive of fossil graveyards, such as the one on the Rancho La Brea near Los Angeles, which has furnished many a museum with glorious exhibits of the mammalian life of the past (Fig. 148).

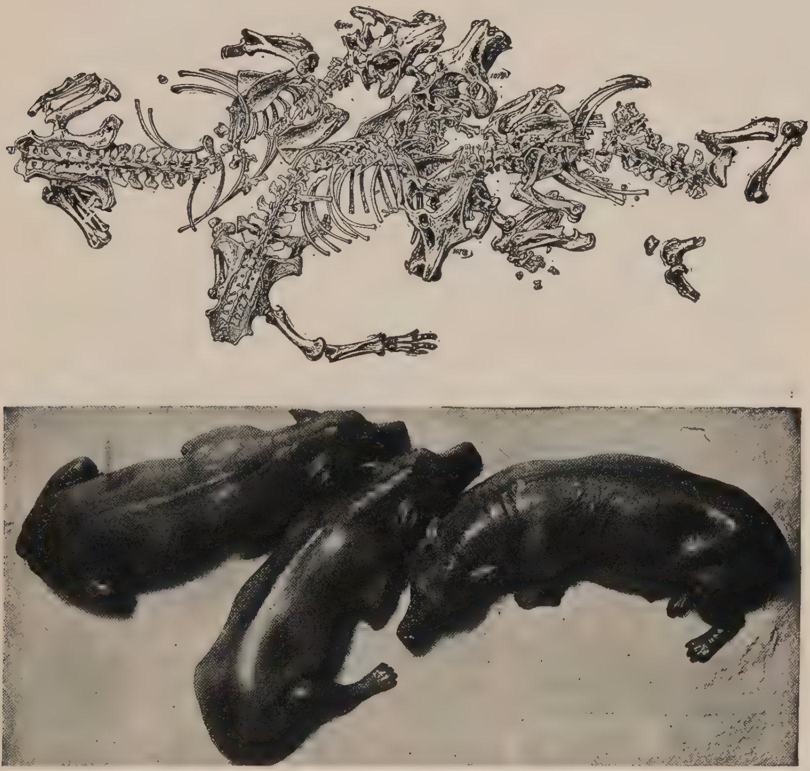


Fig. 5. — A remarkable group of three Miocene oreodonts (*Promerycochœrus carrikeri*), buried by a fall of volcanic ash. Above are the skeletons as found huddled together in the rocks; and below, the animals restored in the flesh. Sioux County, Nebraska. Carnegie Museum, Pittsburgh.

Kinds of Fossils. — The great bulk of animal fossils, as we have seen, consist only of the hard parts, as the external shells or skeletons of calcium carbonate or silica, or the internal bony skeletons, the soft parts having been decomposed away. When to the hard parts of organisms other mineral matter is added, or they are completely replaced by such, the process is called *petrifaction,* which means turning to stone. However, not all fossils are petrified or changed to stone, nor are they necessarily of extinct species, since many living forms of plants and animals are also " found fossil," the degree of petrifaction being no measure of the age.

In general, we may say that fossils usually preserve more or less of their original structure and hard skeletal matter, the amount depending, first, on the nature of the entombing rock (best in calcareous ones), and second, on the porosity and make-up of the strata; siliceous sandstones, for instance, allowing the acidulated waters of the soil to percolate through and thus dissolve away calcareous shells or even bones. On the other hand, fossils may be completely altered chemically, much distorted, or wholly destroyed by heat and pressure resulting from the forces at work in mountain making, when the rocks are made to flow more or less, and to become metamorphosed as in slates, marbles, and schists.

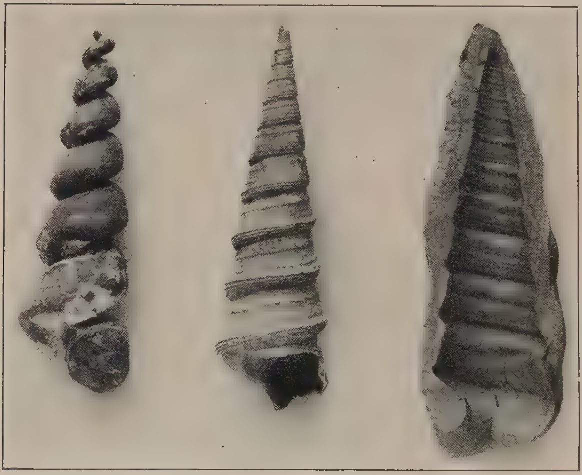


FIG. 6. — Three ways in which the gastropod *Turritella* occurs as a fossil. In the center, the original shell as preserved; at the left, a natural cast of its interior; at the right, a natural mold of its exterior. Peabody Museum, Yale University.

Fossils occur commonly in one of the five following forms:

(1). When the hard parts of organisms are more or less finely porous, the ground waters, with salts in solution, soak through them all the more easily, and fill up these spaces with mineral matter, which may be of the same nature as the skeleton or may be wholly different. The process of addition is called permineralization, and the organisms so treated are *permineralized fossils.*

(2). On the other hand, after the enclosing rocks have been elevated into dry land, the hard parts may be completely dissolved away by the percolating and acidulated ground waters, leaving holes where the organisms have been. These are called *molds.*

(3). Later on the ground waters may fill up these holes completely with mineral matter of various kinds, chiefly calcium carbonate and silica, and then the fossil is called a *cast* or *pseudomorph* (though not all casts are pseudomorphs). (See Fig. 6.) In either case, only the form of the organism is preserved and nothing of the original substance or structure, as may be demonstrated by a microscopical examination.

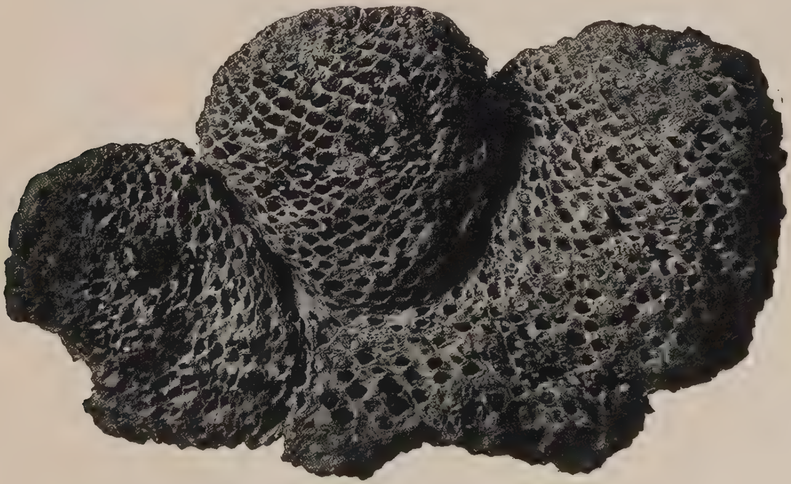


FIG. 7. — A fossil cycad, or plant distantly related to palms. The original wood is replaced by silica, yet the original microstructure is preserved.

(4). A far more interesting form of replacement takes place commonly where wood is buried in sediments through which alkaline waters are circulating, when through infiltration there is molecular replacement by silica, preserving the original cellular structures; the highly variegated " agatized " woods are thus produced (see Fig. 7 and p. 207). Or when the waters are not alkaline the wood may be similarly replaced by calcite, as in the so-called " coal balls " which are found associated with some coals, and are nothing other than balls replete with woody plants in a lime paste. The above described process of replacement is called *histometabasis.* The petrifaction in these coal balls is so perfect that the microscopic anatomy of the ancient plants can be studied in thin sections with almost the same accuracy as if they had just been gathered, instead of having lain buried in the earth for millions of years (D. H. Scott). In other instances, the filtering waters have preserved minutely the contents of the cells, including resin, delicate threads of fungi, even the minute bacteria that cause decay (Knowlton).

(5). Finally, there are imprints, such as those made by leaves (Fig. 123) and insects (Fig. 83), by the feet of walking animals (Fig. 95), by the skin and scales of dinosaurs, and even by jellyfishes, which are more than 90 per cent water. The pelting of raindrops or hailstones on soft muds is likewise frequently recorded (Fig. 95), and from the slant of the pits one can determine the direction from which the storm came.

What Fossils Teach. — The Greek philosophers knew of fossil shells and a few believed they had once been alive in the ocean, but the majority of ancient naturalists held that they were either the work of the devil, placed in the rocks to mystify man, or freaks of nature, made under the influence of the stars, or of a lifegiving force in the ground that they called the *vis plastica*. No advance was possible along this line of thought until the fifteenth century, when Leonardo da Vinci and Fracastoro showed successfully that the many fossil shells then being dug up in the canals of northern Italy were actually once living things, much like those now present in the adjacent seas. Even then, however, these shells were believed to have been spread to places far inland by the Noachian deluge. Their actual nature and the reasons for their occurrence far from present seas were debated for a long time, but no rapid advancement was made until the beginning of the nineteenth century, when William Smith in England and Cuvier and Brongniart in France, as told in Chapter II, demonstrated that each different rock formation has its own characteristic set of fossils. A new geologic science then dawned, that of Historical Geology and Stratigraphy.

The facts established by these workers reacted on philosophy and religion as well as on geology. These sets of different faunas occurring above and below a certain level in the rocks were troublesome to explain if the creation of all life had taken place at one time. Hence arose a belief that instead of a single time of creation, the animals and plants had been wiped out again and again by a series of catastrophes, and that the world had then been repeopled through a series of special creations. This theory served excellently as long as relatively few assemblages of fossils were known, but as more and more were discovered, it became apparent that there were intermediate stages between forms thought to be specially created, and that the whole plant and animal series were linked together. Development of this idea led to the theory of Evolution which we shall take up in the next chapter, and which is mentioned here because fossils had so large a part in establishing its truth.

Further study of the second point of debate, the reason for the occurrence of fossils so far from the present home of similar animals, led to the discovery that the Earth's geography has changed: if marine shells are found in rocks high on a mountain side, for example in the Canadian Rockies 12,000 feet above the sea, the rocks that contain them once lay beneath the waters of the ocean; or if a great sea-turtle lies buried in the rocks of South Dakota, there was once salt water enough in that state for him to swim in!

Not only are fossils demonstrations of Evolution and of ancient geography, but they are, as was said in the previous chapter in connection with the work of " Strata " Smith, dating stamps for the rocks that contain them. This chronogenetic value of fossils is of great import in Historical Geology, since all organic races, like individuals, have a more or less long span of life, and as species and genera are constantly changing, the state of their evolution is indicative of the time of their existence. In other words, each stratum has fossils, or combinations, peculiar to itself, certain forms being so diagnostic as to be called " guide fossils "; these can be used accurately in correlating the strata of a given age from place to place or even from continent to continent. For example, an elephant tooth indicates late Cenozoic time; the imprint of a leaf of a flowering plant, post-Jurassic time; an oyster, post-Triassic time; and a trilobite, Paleozoic time; and all of this the world over.

Comparative Paleontology goes still further than this, and by knowing the trend of evolution in any stock, *i.e.*, having determined the relationship which fossils bear to each other, to those which preceded them, and to their successors, is able to find in the stages of these trends the fossil evidence of the sequence of the rocks which contain them.

In addition to dating the rocks in which they occur, fossils also afford testimony as to the environment in which they lived. Every species of the plant and animal world has a given home or environment known as a habitat, which may be dry land, rivers and lakes, or seas and oceans. Moreover, temperature varies between the poles and the equator, and therefore organisms are cold, temperate, or tropical in their adaptations. All of these differences in habitat are reflected in the fossils. For example, we have learned from many years' study of the corals that they are always to be found in the oceans, never in the fresh waters, and that they make reefs only where the water is permanently warm. Hence the fossil coral reefs which we find in certain ancient rocks of Spitzbergen and Arctic America tell us that the sediments composing these rocks were laid down in warm seas. Again, the leaves of tropical bread-fruit trees, when found in the strata of Greenland, testify to a warm climate at that high latitude when the leaves were buried.

Organisms living on mud bottoms will usually be different from those habituated to sand or lime bottoms, though the freely swimming or floating forms may at death fall on any kind of a substratum. For instance, most bivalves live buried in marine sands or muds, some only in the former, others only in the latter, and most brachiopods and all corals and bryozoans need some hard object or solid bottom to attach themselves to. In other words, organic nature everywhere has the impress of its environment, and through a study of the interactions of Nature in our own time we can learn how to unlock the riddles of the past.

Truly, fossils teach some of the grandest lessons that Nature has to tell us. As Byron well said, " The dust we tread upon was once alive."

CHAPTER IV

EVOLUTION, THE CONSTANT CHANGE OF LIVING THINGS

In the chapter on fossils, the statement was made that the great differences seen between the animals and plants in rock formations that lie unconformably upon each other were at one time explained as being due to re-creations of the organic world after catastrophes; but that as the number of known organisms became greater, and as the "breaks" between the successive formations were filled in from other regions, it was seen that there were intermediate forms linking together the whole procession of life. This idea of the connection of animals and plants in some sort of orderly progression, one developing out of the other, was of long and slow growth, and it remained for Charles Darwin, in his *Origin of Species*, published in 1859 and embodying the results of many years of patient research, to establish firmly the conviction that life has been continuous, descending from previous life, with change, from the most primitive organism to the complex faunas of to-day. The theory met with bitter opposition, the echoes of which have not yet altogether died out, but its truth is now accepted by the biologists of the world as a working principle. Just *how* the process works is not yet fully determined, but the truth of the concept itself is beyond question, even though the *why* is also unknown.

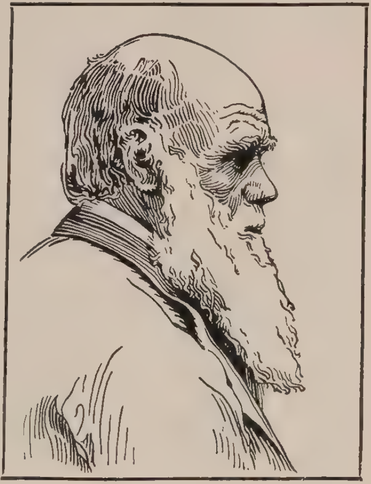


Fig. 8. — Charles Darwin, Father of Evolution.

The evolution concept is without doubt the grandest generalization of the nineteenth century, since it has not only transformed the method of study in Biology, Geology, and the social sciences, but has given a new point of view to all science and art, and even to progressive religion.

The Struggle for Existence. — The compelling factor that lies back of evolution is the familiar one of competition, which, in the organic world, is a struggle for the very chance to live and produce offspring. This is the aptly termed *struggle for existence,* and the reason for it in turn is often the same one that frequently leads to great human wars — overpopulation. The prodigality of organic nature is beyond comprehension, and equally so is the wastage of individuals. More young are born each year than can possibly exist. Some individuals produce but a single offspring, while others cast upon the world many millions during the season of reproduction. Life's struggle is exceedingly harsh toward the young; they are mercilessly weeded out because of unfavorable habitations and starvation, snapped out of existence by a predaceous enemy, or made sick unto death by extremes of heat or cold, or by bacterial diseases. *Success in life is the rare exception.*

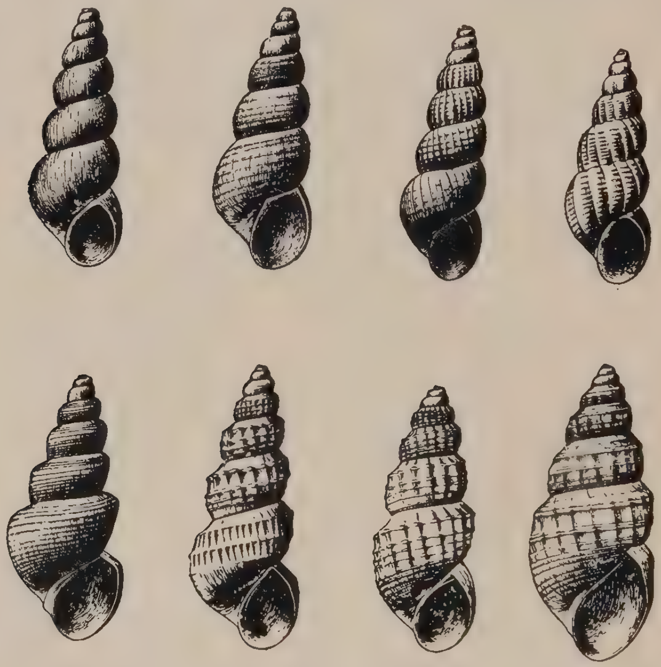


FIG. 9. — Variations in the shell of a single species of the living gastropod *Paludestrina.* From Metcalf, after Stearns.

Variation. — In a struggle so severe, any advantage, however slight, may therefore be decisive in prolonging the life of the individual. To take a specific example of the very simplest sort, if two animals are left stranded somewhere with food enough for only one, that food will go to the stronger (or the cleverer or the swifter, as the circumstance may be), animals seldom being inhibited by "brotherhood" complexes. And in the fact that one of the two *is* stronger or cleverer or swifter, or that the stock has some advantage, however slight, lies the starting point of evolution. In other words, no two animals are exactly alike. While it is true that each species " breeds true " in its specific characters, so that no English sparrow ever turns into a song sparrow, nevertheless no two English sparrows are exact copies one of the other. This tendency-to-vary, or variation, produces the slight advantage that may make it possible for an animal to survive when every one of his fellows perishes — the process well known under the name of *the survival of the fittest.* As a stock breeder eliminates from his herds the weaklings and undesirables, so Nature through this constant struggle for existence eliminates the unfit, and the fit are left to produce the next generation. Such weeding out by Nature was called by Darwin *natural selection.* The student should clearly understand, however, that natural selection is not capable by itself of giving rise to new characters; all that it does is to weed out the unfit and chiefly the feeble and sickly.

Long before evolution was established by Darwin, breeders of animals had been taking advantage of marked variations (not the slight ones). For example, our domestic dogs, which range from the solemn Great Dane to the sleeve dog of patrician China, have all been developed in this way from a single common ancestor. The breeders observed that from time to time an individual appeared that differed quite considerably in some detail from his brothers and sisters — perhaps he had longer legs or a shorter nose! The new character proved to be inheritable, that is, if the dog possessing it were mated with another which had a similar tendency, and the same selection exercised among their offspring, a new breed would eventually be established. It is the belief of geneticists, that it is not the slight fluctuations in form that are inheritable, only the more marked mutations; it may be, however, that all changes are inherited. The use of such mutations by breeders is Darwin's *artificial selection;* "Man," he said, "selects only for his own good; Nature only for that of the being which she tends."

Heredity. — The fixation of advantageous variations, or, better, the suddenly appearing and inheritable *mutations,* depends, then, upon *heredity,* which passes them on, generation after generation. It should be understood that mutations are of various degrees of difference, mostly very slight indeed and only rarely marked. On the other hand, organisms may alter much during their lifetime, but these variations are not apparently inheritable and therefore have no effect on their offspring. But if the difference is inheritable, the tendency to vary along a particular line or lines will remain, and either be latent or manifest itself in the individuals of subsequent generations. In other words, every one of the countless differences between the animals and plants which are living to-day represents a mutation which has occurred at some previous time. Evolution is thus nothing more than an " accumulation of mutations " (Coe).

The whole process of selection and inheritance usually works with exceeding slowness in Nature, and what we see in the living world and the geologic past is the result of organic reproduction with change through 1500 million years. Moreover, evolution is not always a steady forward progression from simpler or lower to more complex and higher organisms, but often the very reverse, as is so strikingly shown over and over again, among animal parasites and other degenerate stocks. On the other hand, there are many plants and animals which have changed very little for hundreds of millions of years, for example the living lung-fishes (sometimes called "living fossils"), which are much like those of Paleozoic times.

The Mechanism of Evolution. — The biologists, in their pursuit of the science of genetics, which deals with variation and heredity, have probably discovered the mechanism which brings about heredity and mutations. The present work, however, is not the place to enter into this very intricate subject, but the student who wishes to investigate it further will find it excellently summarized in a paper by W. R. Coe, cited in the reading references at the end of this book. A new vista has recently been opened, as pointed out by H. J. Muller in 1927, by the discovery that the shooting of radium emanations through organic cells causes the mutations to increase 150 times over the normal rate, which may mean that artificial selection, as carried on by breeders, can now be speeded far more rapidly than it takes place in Nature.

Influence of Environment on Organisms. — So long as the environment remains unchanged, plants and animals undergo comparatively little modification. But in detail the environment is never constant, since from time to time the Earth's shell rises into mountains or the oceans flood widely over the continents. Hence it follows that the environments have undergone repeated and vast alterations. When mountains are thrown up simultaneously in many lands, great changes in the humidity and temperature of the atmosphere result, bringing on arid climates and even glacial ones. Such times are fraught with danger to the organic world, and from time to time animals and plants are forced to face these severe physical changes, which call for tremendous readjustments to meet the newly arisen conditions. Think of the struggle for existence when moist climates change to those of a desert, as when the Sahara succeeded the moist Eocene landscape of northern Africa; or when temperate climates change to cold and icy ones, as happened three or four times to North America during Pleistocene time! Evolution is then especially rapid, floras and faunas that have long dominated the Earth are blotted out, and some of the small and insignificant stocks are given the opportunity to take the lead and rise into new races that in their turn comparatively quickly attain mastery over their physical and organic environment.

Evolution and the Paleontologist. — In the living world we often find all or most of the links connecting related species and sometimes related genera, but in the vast majority of instances our hunt for the steps in the ancestral lines takes us back into geologic time, and the greater the groupings the farther back we have to go: for family origins, often into medieval times, and for most orders back into the Early Paleozoic, while the origin of the phyla goes back to the Proterozoic. In other words, there are no such things in the living world as " connecting links " between the larger groups, but only such as occur between genera and between species. This means that most of the evidence for evolution in its broader lines, that is, from family to family, or from phylum to phylum, has been, or can be, furnished only by the paleontologist, who is in an especially favorable position to observe it, seeing as he does the procession of life during the geologic ages. Unfortunately, however, the geological record is very imperfect.

From the accumulated observations of these students of ancient life, we now know that the history of the Earth begins in obscurity, with an absence of all life. At the very beginning of the third great era, the Paleozoic, however, there is an abundance of marine forms, but nevertheless for a long time there is no evidence of land plants, and a land flora does not appear until still later times. The earliest animals all lived in the oceans, and out of them arose forms which could also breathe air and therefore could live on the land. Not a shred of evidence is at hand for the existence of animals with backbones (vertebrates) until long after the backboneless forms (invertebrates) originated, the first representatives of the higher type being the fishes. Later came the amphibia, out of which developed the primitive reptiles. Reptilian birds with teeth appeared after the reptiles, and these gave rise to the modern toothless birds. Reptilian mammals, on the other hand, originated earlier than the birds, and through a long and slow process of evolution finally gave rise to the placental mammals, the highest type of animals. Finally, the line of mammals leading to man appeared first in the lemurs (monkey-like forms), shortly afterward came the true monkeys, and more recently arose the anthropoid apes and the ape-man.

This periodic appearance of new stocks of plants and animals, connected in the main with marked changes of the environment, is deeply impressive to the paleontologist, who therefore holds that it is the periodically changing physical conditions that are the greatest impelling force in organic evolution. On the other hand, the long intermediate

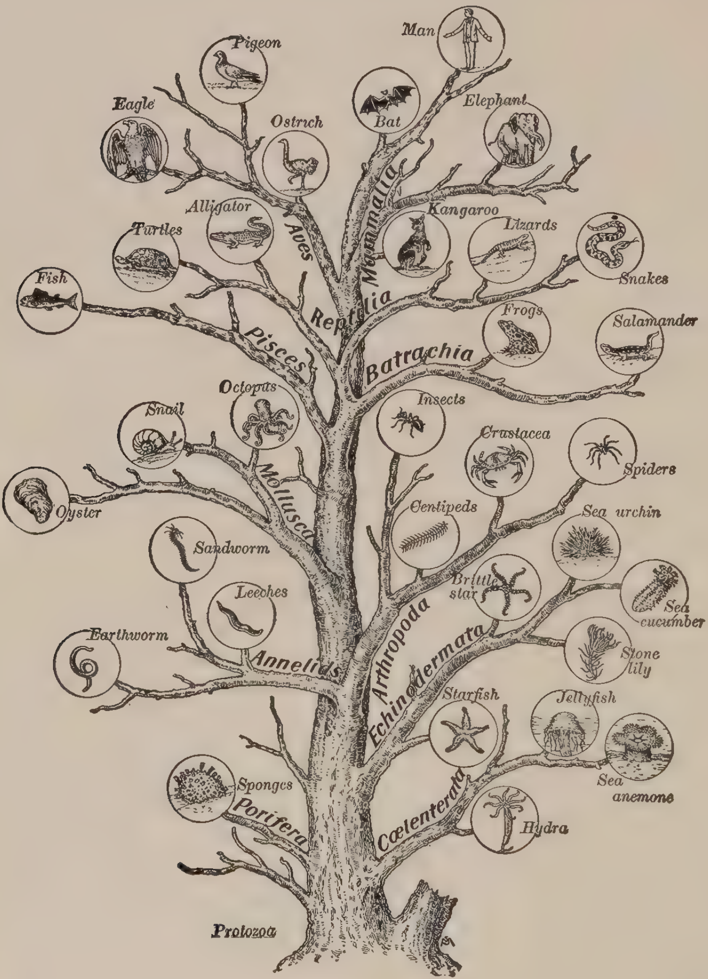


Fig. 10. — Generalized tree of animal life, showing only the main branches (phyla), and not always in their genetic relationships. The diagram suggests the common origin of all animals in succession, with constant progressive change from the lowest (Protozoa) to more specialized types, and culminating in mammals and birds. The branching of a tree is usually taken to symbolize this interrelationship. For more detail, study Fig. 19. From Gruenberg's *Elementary Biology* (Ginn and Company).

times of equable and mild climate and nearly constant environment produce but slight specific alterations. Therefore evolution appears at times to proceed far more quickly, and as it were by leaps and bounds. These are the times of quickened adaptations to meet the great changes in the environment, while a slow or even stagnant evolution accompanies the long intermediate periods.

CHAPTER V

AN INTRODUCTION TO PLANTS AND ANIMALS

I. PLANTS

While no actual count of the kinds of plants and animals living to-day has ever been made, the estimates are yet near enough to give us a proper realization of their extraordinary diversity. The plants, though far exceeding the animals in abundance of individuals, are nevertheless much less diversified, their total number of kinds being 265,000. On the other hand, of animals about 825,000 kinds have been named and described, and of these 645,000 are species and varieties of insects, whereas the more familiar vertebrates muster only 35,000 different sorts. In the vast marine realm, which has a far more equable and monotonous environment than the lands, some 100,000 forms of animals are living, contrasting markedly with the 725,000 known kinds on the land. The fresh waters of the lands, strange as it may seem, have the least variation, furnishing homes to about 20,000 kinds of animals, one-half of these being fishes, while the molluscs are present to the number of 4000. Looked at in another way, there are more than twenty-two times as many kinds of the lower forms of living animals (invertebrates) as there are of the higher vertebrates.

Classification of Plants and Animals. — It must be self-evident to all thinking persons that with such vast hordes of organisms as have been indicated above, there must be some universal language that naturalists use in talking about them, since the common name of a plant or animal might be different in every language. Man has long been concerned with this problem: in fact, we are told that it was Adam who gave the popular names to animals in the Garden of Eden as they were brought before him, " and whatsoever name he gave, that is the name therefor." Here is great precedent, also, for the law of priority in biologic nomenclature, a principle now followed by all systematists, which says that the first name given to any species in a way that makes it recognizable must be accepted by all who subsequently write of this species.

The present method of naming organisms so that they will be recognizable to scientists of all countries is a binomial one invented between 1735 and 1758 by a great Swedish naturalist, Carl Linné (or Linnæus). It gives to each form two names, taken from Greek or Latin, the latter of the two indicating the particular individual *kind* (species), and the former the general *tribe* of species (genus) to which it belongs. To illustrate: the catlike animals — domestic cat, lion, tiger, leopard, etc. — form an obviously similar tribe and all bear, therefore, the generic name *Felis* (from the Latin *felis*, a cat), to distinguish them from other tribes of carnivores such as the dogs (*Canis*) or the bears (*Ursus*). But the distinct kinds of cats bear individual specific names; thus the domestic cat is *Felis domestica*, the " king of the jungles " is *Felis leo*, the tiger is *Felis tigris*, and the spotted cat is *Felis leopardalis*.

Once a plant or animal has received a name, the next question is: What are its nearest relatives? In other words, to what larger group does it belong? This instinct for " pigeon-holing," *i.e.*, classification (which seems to be universal), is already apparent as far back as Aristotle (384 322 B.C.), who was the first naturalist to begin the grouping of animals, dividing them into red-blooded (= vertebrates) and bloodless (= invertebrates). Time has shown that the two divisions are correct, but that the basis for their distinction is erroneous.

The first impulse toward our modern ideas of classification came from Baron Cuvier (1769–1832), famous paleontologist of the Paris Museum, who presented the idea that all animals belong in one of four " branches," typified as it were by a great branch of a tree (see Fig. 10). This scheme we still follow, but we have increased the number of main branches to at least fourteen, each thought to represent one fundamental genetic line (= line of descent), and we call them *phyla* (from the Greek *phylon*, stock or race).

In the following incomplete lists, the phyla marked + are known back as far in geologic time as the Proterozoic era, those marked ++ as far back as the Cambrian; the rest originated at some later date, as indicated.

PHYLA OF PLANTS

+Thallophyta (Protophyta), algæ, fungi, bacteria, diatoms, etc.
Bryophyta, mosses and liverworts. (Devonian.)
Pteridophyta, ferns. (Devonian.)
Arthrophyta, horsetails or rushes. (Devonian.)
Lepidophyta, scale-trees. (Devonian.)
Pteridospermophyta, seed-ferns. (Devonian.)
Cycadophyta, cycads. (Triassic.)
Coniferophyta, conifers. (Devonian.)
Angiosperma, hardwood trees and flowering plants. (Jurassic.)

PHYLA OF ANIMALS

+Protozoa, unicellular micro-animals.
+Porifera, sponges.
++Cœlenterata, hydroids, graptolites?, jellyfish, actinians, corals, etc.

Platyhelminthes, flatworms. (Not known as fossils.)
Nemathelminthes, roundworms. (Not known as fossils.)
$^{++}$Molluscoidea, bryozoans and brachiopods.
$^{++}$Echinodermata, starfishes, sea-urchins, feather-stars, etc.
$^{++}$Mollusca, snails, clams, cephalopods, etc.
$^{+}$Annulata, earthworms and other segmented worms.
$^{++}$Arthropoda, crayfish, lobsters, insects, spiders, centipeds, etc.
Chordata, tunicates, etc., and vertebrates. (Ordovician.)

No new animal phylum has been evolved since the coming of the vertebrates (fishes) in the older Paleozoic (Ordovician), and no new classes since the appearance of the mammals and birds of the Early Mesozoic (Jurassic). Hence nearly all of the phyla indicated in the table trace their origin very far back in time, at least eight being present (and probably two more) in the Cambrian, and of these at least three are known from fossils in the Proterozoic (protozoans, sponges, and segmented worms).

The phyla are broken up into smaller divisions, and also grouped together into broader ones, the highest division (kingdom) representing, so to speak, the trunk of a tree, and the divisions of smaller and smaller import being its branches, branchlets, and twigs. For example, in the parlance of the systematic zoölogist, the complete classification of the dog is expressed as follows:

Kingdom Animalia, animals.
Phylum Chordata, vertebrates.
Class Mammalia, mammals.
Order Carnivora, carnivorous mammals.
Family Canidæ, dogs, wolves, foxes.
Genus *Canis*, dogs.
Species *familiaris*, domestic dogs.
Individual, Handsome Dan.

The Plant Kingdom

As is now generally held, the plants originated first, and it is widely believed that they arose in the sunlit portions of the oceans in the form of single-celled, microscopic, floating globules. Some organic chemists, on the other hand, prefer to think of plants as starting in hot waters, a view supported by the fact that certain of the most primitive forms of algæ (blue-green forms and bacteria) live to-day in boiling hot waters such as those in Yellowstone Park (150°–170° F.). However, the lowest forms of single-celled plant and animal life are so much alike that it is probably best to say that the first life was neither, simply primordial

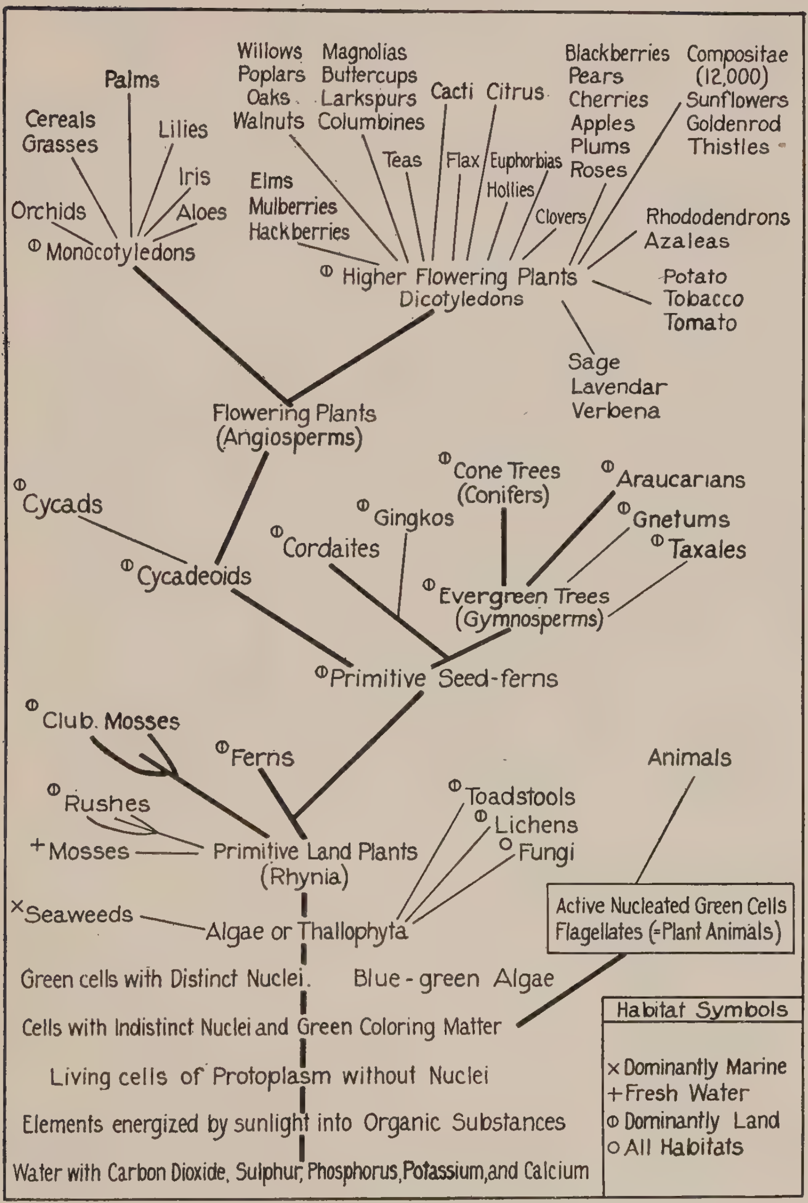


FIG. 11. — The evolution of plants. Main lines of ascent in heavier black. From Schuchert and LeVene's *The Earth and its Rhythms* (Appleton).

life. Through trial and error, in the struggle against a changing environment, this primordial life eventually diverged along two lines: (1) forms attending more strictly to the conversion of inorganic materials into living compounds, constituting the Plant Kingdom; and (2) the feeders upon this organized material, making the Animal Kingdom. Plants have always been either directly or indirectly the source of food for all animals.

All plants, we may say, reproduce either through spores or seeds. A *spore* is usually microscopic in size, being an unfertilized cell of protoplasm which, under proper growth conditions, will reproduce the kind of plant that gave origin to it; it is the simplest form of reproductive body. A *seed*, on the other hand, is an embryo accompanied by food enough to sustain it until it can take root in the ground.

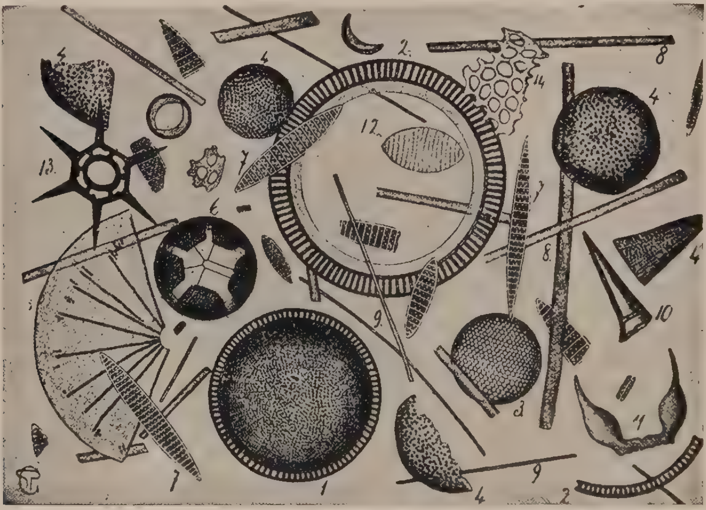


Fig. 12. — The siliceous tests of many species of diatoms, washed out of Antarctic diatom ooze. × 300. From Krümmel's *Oceanographie.*

Paleozoic floras differed radically from the later ones not only in their general appearance but in their mode of reproduction as well. In these early floras the great majority of plants did not reproduce by seeds but by spores, the male parts being washed by the rains and winds upon the female germs.

Different botanists group the plants in various ways, but for our purposes we may arrange the common fossil and living ones into eight phyla, as follows:

Thallophytes, or thallus plants (Greek *thallos*, a young shoot), are the simplest living forms of vegetation — merely green shoots, not as yet differentiated into root or stem or leaf, and all reproducing by spores. They are rare as fossils, and those that do so occur — diatoms (Fig. 12), seaweeds, and certain lime-secreting types — as a rule preserve the gross form only and nothing of the plant structure. Probably the majority are one-celled (bacteria, etc.), though some of the seaweeds attain lengths of 100 feet. Of importance in Geology are the coralline and nullipore algæ that secrete calcium carbonate and thus make at times extensive limestones; probably one-half of the modern "coral" reefs are composed of these forms.

The phylum *Arthrophyta* includes at present only the horsetails or rushes — slender pipe-like stems rough to the touch and hence called "scouring rushes" by pioneer housewives who used them to keep their pans bright. They reproduce by spores. The stems look as if they were put together in sections, whence the name, which means "jointed plants" (Fig. 13).

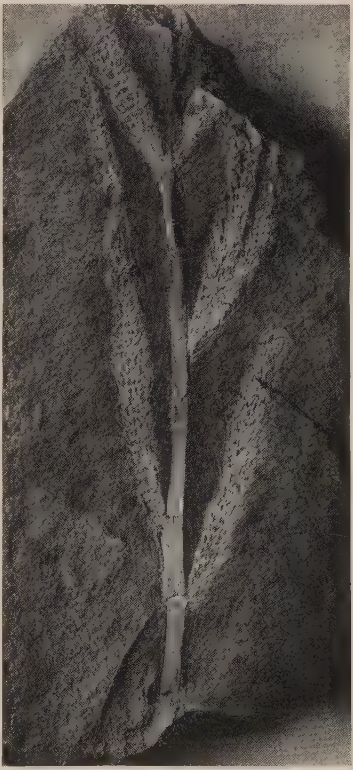


Fig. 13. — A fertile shoot (*Calamostachys lanceolata*) of one of the calamites, with cones and spores. Original in U. S. National Museum. From Knowlton's *Plants of the Past*, by courtesy of the Princeton University Press.

In the living world occur commonly some twenty species of small horsetails, usually less than 18 inches tall, though one American tropical form attains 30 feet or more. The floras of Late Paleozoic time, however, had a great abundance of these, some of which were of great size, the largest ones, called *calamites* (Fig. 14, *B*), growing in thickets to a height of 60 feet, while some forms went to 100 feet. Another similar group were the small *sphenophylls*, long extinct, and both stocks appear to have had a common origin; the sphenophylls are the more interesting to the paleobotanists, since they are thought to have given rise to both the ferns and the club-mosses.

Most highly developed of the spore-bearing plants are the *Lepidophyta*, or scale-plants. In the living world of to-day the lepidophytes are neither common nor varied, including mainly the creeping ground pines or club-mosses so generally used for Christmas decorations. The fossil forms, however, grew to over 4 feet in diameter and topped 100 feet in height.

The most conspicuous Paleozoic lepidophytes were the strange scale- and seal-trees, so named from the shape of the scars left by the leaf bases on the trunks and branches. *Lepidodendron*, the scale-tree, differed from modern trees in that the trunk and many of the branches divided into two forks rather regularly (Fig. 17, *A*). The leaves were needle-like, and many of the branches ended in cone-like spore cases. *Sigillaria*, the seal-tree, was unlike *Lepidodendron* in being rarely branched, and in bearing erect grasslike leaves toward the top only (Fig. 14, *A*). Neither of them has living representatives.

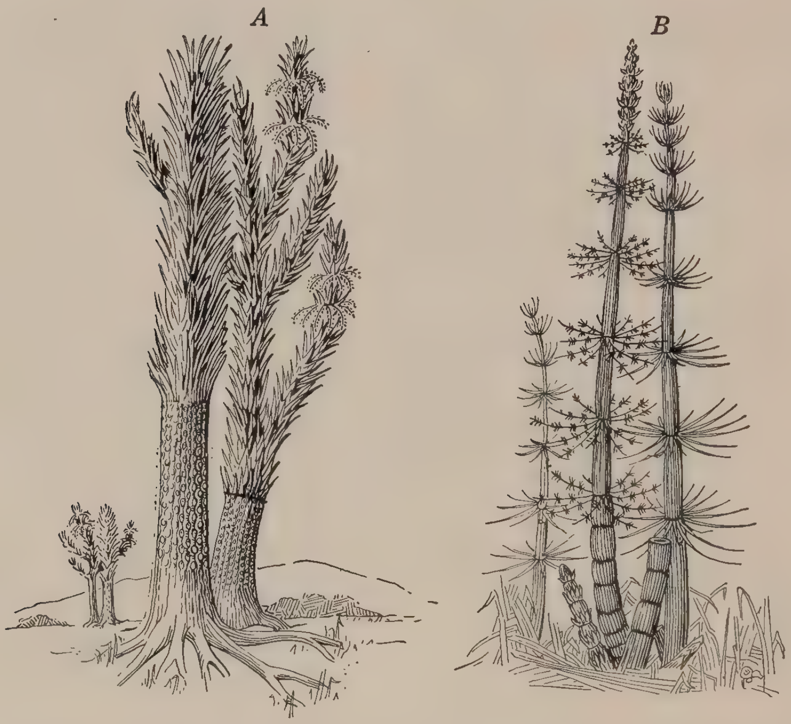


Fig. 14. — Trees of the Pennsylvanian coal forests. *A*, *Sigillaria*, known as the seal-tree from the impression of the leaf bases. *B*, one of the ancient rushes, or calamites, not unlike a modern one in appearance, but growing to a height of 100 feet.

Phylum *Pteridophyta* includes the familiar ferns. The name comes from the Greek word *pteris*, meaning fern, but derives from the same stem as the word for feather or wing, the Greeks recognizing the "feathered " appearance of the fern leaf. The ferns have stems, leaves, roots, and true " woody " (vascular) structures. Their tiny spore cases are often grouped on the under sides of the leaves, and a single plant may produce and shed 20,000,000 to perhaps 50,000,000 spores. The ferns are of ancient origin, going back to at least Middle Paleozoic time, and Figure 15 shows how little a fern of that era differed in general form from a living one. In size, the living ferns vary from the familiar woodland types to tropical tree-ferns with a trunk 2 feet or more in diameter and 60 to 70 feet in height, having a crown of large spreading fronds at the summit.

Fern plants were in their heyday in the Paleozoic, and appear then to have made up half of the floras. Some were delicate, others hardy or climbing, while many grew into trees some of which were as high as 70 feet.

Pteridospermophytes, or seed-ferns, were the first group of plants to grow seeds, and out of them all the higher seed plants directly or indirectly developed. They are found in the Early Paleozoic alongside of the true or spore-bearing ferns, and are so like them in foliage and general growth that the two can be distinguished only when their reproductive structures are preserved.

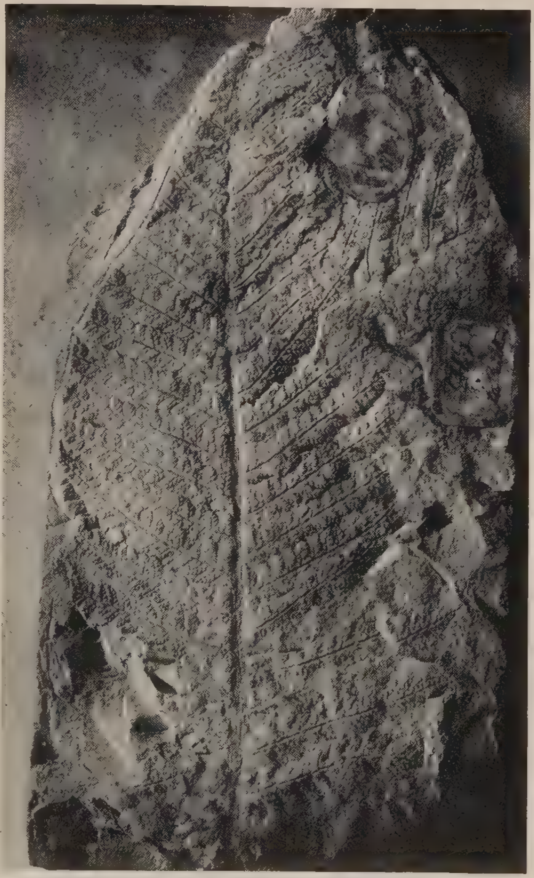


FIG. 15. — An ancient fern (*Pecopteris dentata*) from the Pennsylvanian of Missouri. Original in U. S. National Museum. From Knowlton's *Plants of the Past*, by courtesy of the Princeton University Press.

From the botanical standpoint, the seed-ferns are the most interesting of the Paleozoic floras. The presence of seeds was a great forward step in the evolution of the plant world (in some of the forms the seeds were as large as ducks' eggs), and reproduction by the seed method was to become the dominant feature of later floras. Of the fernlike plants of the Carboniferous more than half reproduced by seeds. Figure 16 shows one of these pioneers in seed-bearing.

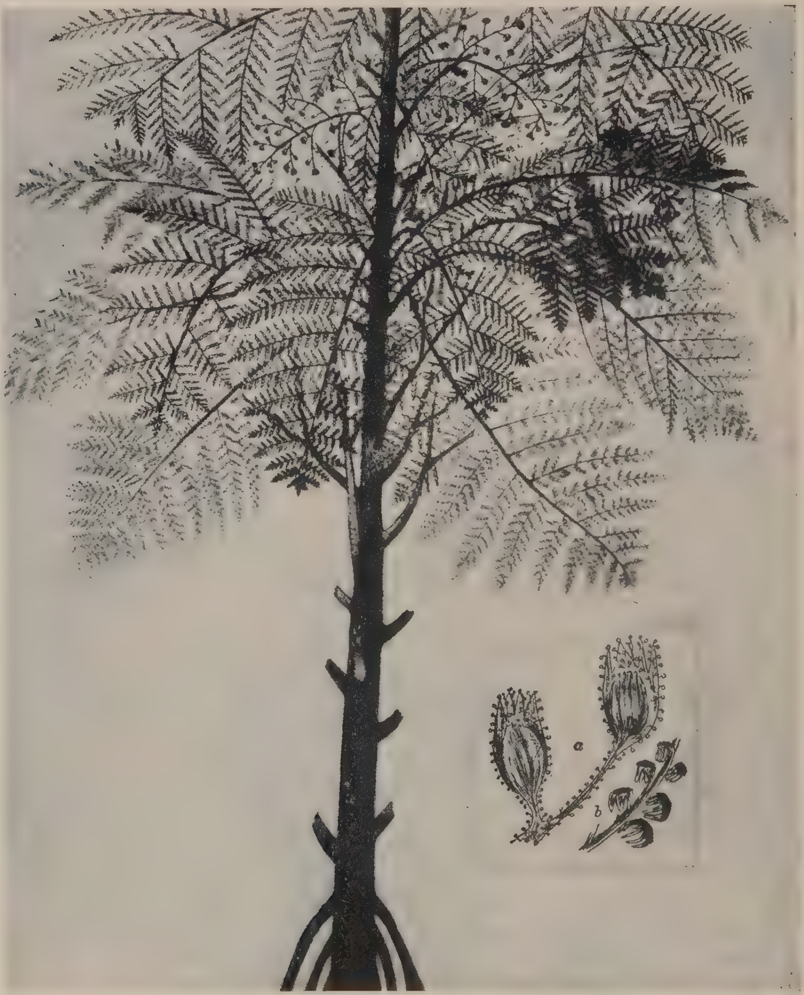


FIG. 16. — Restoration of a seed-fern (*Lyginodendron oldhamium*) from the Upper Carboniferous of England. Modified after Berry. *a*, seeds; *b*, male organs. After Scott. From Knowlton's *Plants of the Past*, by courtesy of the Princeton University Press.

The *Coniferophytes*, or cone-bearers, are still more familiar, including the pines, redwoods, junipers, sequoias, and cypresses. They, too, go back to Early Paleozoic time; in fact they made up the greater part of the ancient forests of the uplands. The common Paleozoic kinds, named *cordaites* after the botanist Corda, were softwood forest trees like our modern conifers, from which, however, they differed chiefly in two respects: (1) their leaves were long — in some forms a yard long — and straplike (never needle-like); and (2) their seeds were in loose racemes or clusters instead of compact cones (Fig. 17, *B*, *C*). The cordaites died out in the Early Mesozoic. A related stock comprised the *maidenhair trees*, so called because in the only living species the leaves resemble those of the maidenhair ferns.

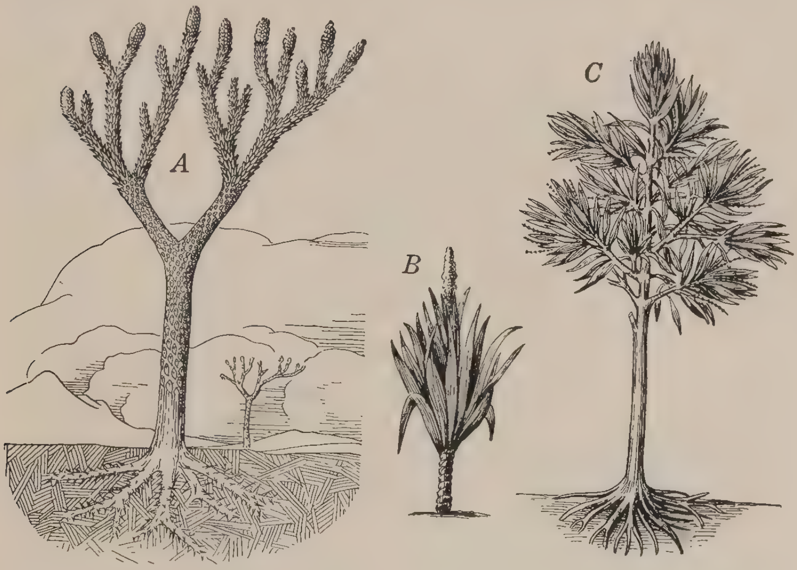


Fig. 17. — Trees of the Pennsylvanian coal forests. *A*, *Lepidodendron*, the scale-tree, so called from the scalelike look of the leaf scars. *B* and *C*, two of the cordaites, conifers that were exceedingly common.

The phylum *Cycadophyta* is represented to-day by such tropical plants as the sago "palms" (Figs. 18, 91). While in general they resemble true palms in their leaves, the palms are genuine flowering plants and belong to the phylum Angiosperma. Cycads may have a small trunk, mostly buried in the ground, or one that attains a height of 50 to 60 feet; the trunk very rarely branches, and has at the top a cluster of more or less large palm-like leaves; the flowers are often showy but the seeds are more primitive than in the angiosperms. They are now almost entirely confined to the southern hemisphere, though two species live in Florida; in medieval times they lived all over the world (see Chapter XV).

The highest of all plants are the hardwood trees and the beautiful flowering plants, included in the phylum *Angiosperma,* of which at least 125,000 kinds have been described. They are all, of course, seed-bearing, but show a great advance over the other seed-bearing phyla in that

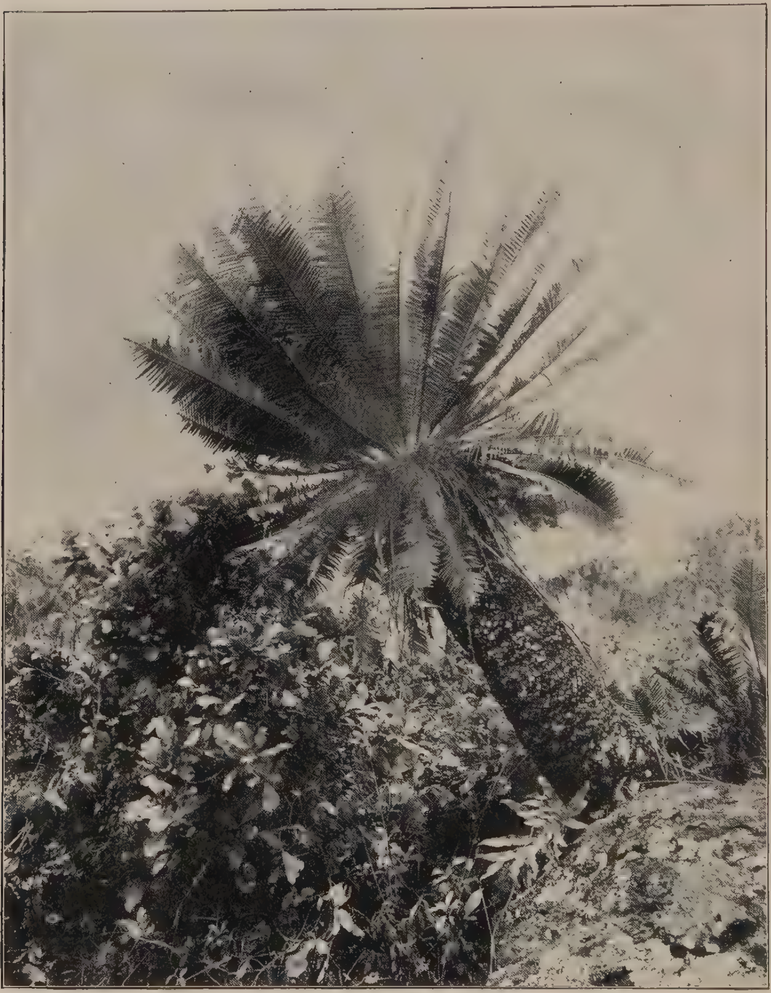


FIG. 18. — *Dioon edule,* a living cycad from Mexico. After Chamberlain, from Coulter and Chamberlain's *Morphology of Gymnosperms.* Reprinted by permission of the University of Chicago Press.

their seeds are protected in a closed receptacle called a capsule or ovary. For this reason they are known as angiosperms (covered seed) in contradistinction to the gymnosperms (naked seed), which include the seed-ferns, conifers, and cycads.

As early as Devonian time, says the paleobotanist Knowlton, "certain fernlike plants had already hit upon the seed-bearing plan, but they lacked the advantage of the true seed plants, which when mature have a tiny plantlet or embryo already developed in the seed, with a supply of food sufficient to keep it going until it is established in the soil, and becomes, so to speak, self-supporting. But the production of true seeds in a closed vessel or capsule, with all that goes with it, was apparently the magic touch needed to start them on their conquest of the world."

The angiosperms are at present so dominant in the plant world as to form more than one-half of our total flora. They have met the test of every climate, from 14,000 feet in the Bernese Oberland of the Alps to the scorching deserts of Africa. Only in the seas have they failed to succeed, for here the master rôles are still played by the original inhabitants, the humbler Thallophytes.

Flowering plants depend very largely upon insects for their cross-fertilization, as everybody knows; attracted by the sweet odors and high colors of the flowers, the insects crawl in, become dusted with pollen, and so carry the fertilizing germs from flower to flower and from plant to plant. Hence it is no surprise to see the higher insects appearing in Earth history at the same time with the flowering plants, the interdependence between them apparently being established at an early period.

CHAPTER VI

AN INTRODUCTION TO PLANTS AND ANIMALS

II. ANIMALS

Animals are arranged in two subkingdoms, Invertebrata and Vertebrata. We may define invertebrates as animals without a longitudinal internal dorsal axis (= backbone), though there may be an external skeleton in the form of a shell, or a stiffened framework of some kind buried in the skin (as in echinoderms). The vertebrates, on the other hand, have internal skeletons. These subkingdoms are in turn divided into phyla, concerning the number of which there is as yet no unanimity among systematists, though most of them agree upon the following eleven (see page 35):

Phylum Protozoa. — Comparable in position to the simple Thallophytes among the plants, the Protozoa embrace a world of microscopic and highly varied one-celled invertebrates — " animals reduced to the lowest terms." Although the vast majority are individual tiny single cells, there are colonial forms among them, but in these, each individual or cell leads an independent life despite the fact that the colony has definite form and moves as a unit; that is, each secures its own food, digests it, discharges its own waste products, and reproduces its kind. Protozoa are the most abundant animals, but all are inconspicuously small, their size range being from a point below the power of the microscope, as in certain of the disease germs, to that of *Porospora* " *gigantea,*" a lobster parasite, which attains a length of two-thirds of an inch. As we saw in the discussion of the Thallophytes, certain of the simpler forms are on the borderline between the plant and animal kingdoms.

Of the many sorts of Protozoa, the only ones needing emphasis here, as common fossils, are the Foraminifera and the Radiolaria. The *Foraminifera* (Fig. 20, *B*) are tiny marine animals each consisting of a globule of protoplasm with a calcareous chambered shell that is usually perforated by openings or foramina, whence the name. They are found in all seas down to about 2500 fathoms. Tiny in themselves, they occur in such unbelievable numbers that their shells, sinking to the bottoms, form the deep-sea oozes such as are described in Chapter VIII of Part I. The fact that most of them have a calcareous shell accounts, of course, for their preservation as fossils since early Ordovician time.

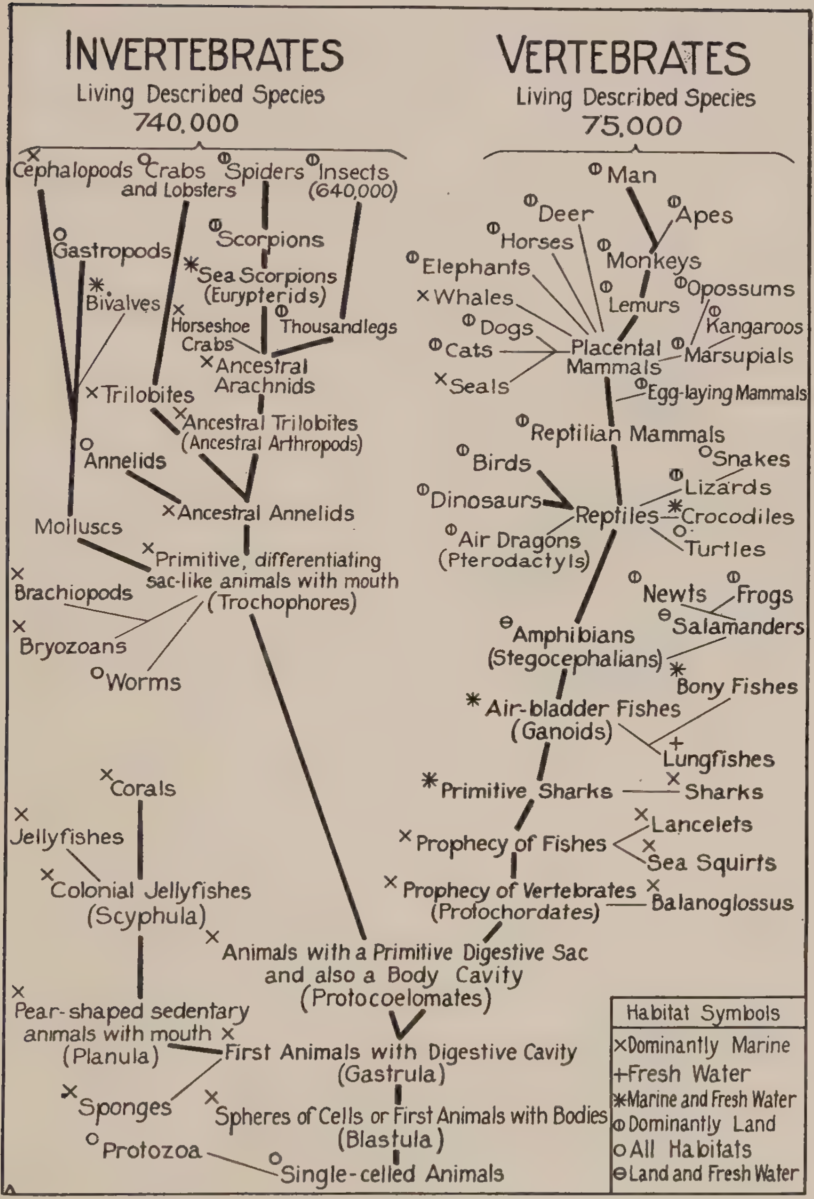


FIG. 19. — The evolution of animals. Main lines of ascent in heavier black. From Schuchert and LeVene's *The Earth and its Rhythms* (Appleton).

Of recent years, their importance as guide fossils is increasing, since they have been found to be very useful horizon markers in the oil fields.

A second group of Protozoa, also ooze-makers, are the *Radiolaria*, which have highly ornate skeletons of silica that are never chambered (Fig. 20, *A*).

Phylum Porifera or Sponges. — In these, the lowest of the many-celled animals (Metazoa), as contrasted with the one-celled Protozoa, the individual is composed of aggregates of cells. Among these cells, there is some division of labor, but there is no digestive tract to serve the combined cells, as in the next higher group, the cœlenterates. The sponge skeleton is either of spongin, as in our wash sponges, or of calcium carbonate, or of silica (Venus' flower basket). The phylum has been in existence since middle Proterozoic time, but it is not a progressive one, and has given rise to no higher organisms. (Fig. 21.)

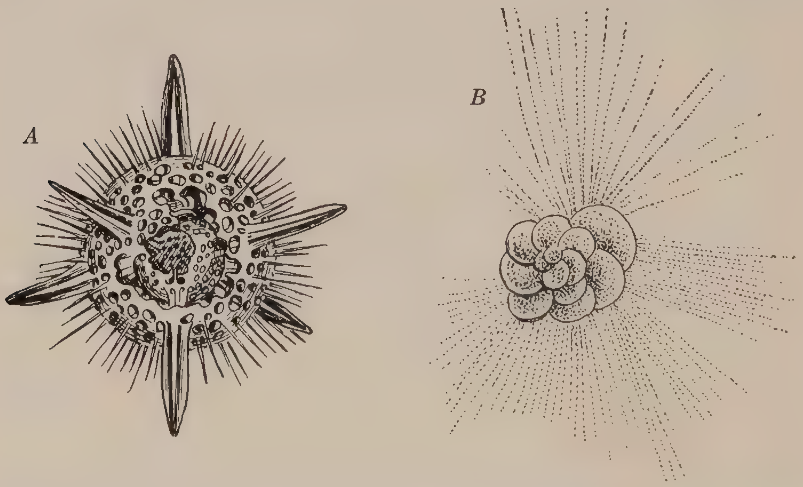


FIG. 20. — Two of the living Protozoa. *A*, *Actinomma*, a radiolarian; *B*, the foraminifer *Rotalia*. Redrawn from Weysse.

Phylum Cœlenterata (from Gr. *koilos*, hollow, since they have a body cavity for digestion, but no gut). — These are flower-like animals built on the radiate plan, and include the hydroids and jellyfishes, the sea anemones and their close relatives, the stony corals. The digestive sac, which practically constitutes the whole animal in the simpler forms, has the free end surmounted by numerous food-getting tentacles, and there is but one opening, functioning as both mouth and anus.

This phylum contains such an extraordinary variety of living animals that we will not attempt to describe them here, since but few of the kinds are found fossil. And yet out of this highly diversified phylum no higher type of organization came. All the kinds start as free floaters, and some stay in this condition, but most of the cœlenterates are attached to the sea bottom and develop radial symmetry.

Of the cœlenterates, it is only the " stony " *corals, i.e.*, those having external calcareous skeletons, that are common as fossils (Fig. 22). Due to their bright colors, their radial symmetry, and their spreading tentacles, living coral animals present a flower-like appearance, but their calcareous or horny skeletons are of frequent occurrence in rocks from the Middle Ordovician on. The stony corals thrive in the warm, clear, and shallow waters of the tropics and subtropics, and for this reason fossil coral reefs always bear an interesting climatic implication. It must not be overlooked, however, that corals do live in cold and even very deep oceanic waters, though here they build no actual reefs. Some solitary forms have been dredged at 15,000 feet. Off western Europe four species live in a range from 600 to 8000 feet; and in places where the temperature is not lower than 44° F., and the depth between 600 and 1200 feet, they are so common as to make accumulations resembling reef-limestones.

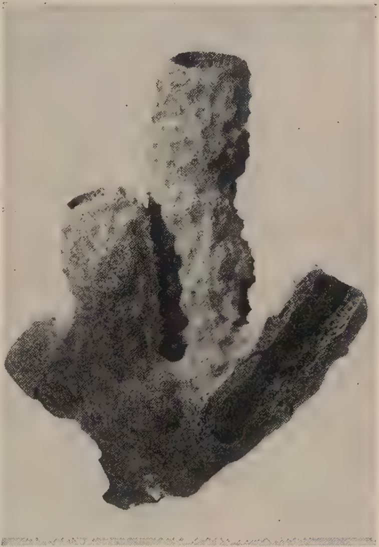


Fig. 21. — A modern sponge, *Spongiella.* The individual at the right has been cut through to show the cavity of the body, devoid of visceral organs. Miami Beach, Florida.

The extinct *graptolites* (Fig. 24) were possibly also cœlenterates, though excellent authorities say they were bryozoans. They were creatures of minute size which lived in linear colonies, being lodged in pits or cups along chitinous stalks. Their tough but pliable external tests are often very common in black shales of the Early Paleozoic, and resemble writings on stone, hence the name (Gr. *graphein,* to write, and *lithos,* stone; see Fig. 60).

The sponges and the corals were destined to remain sedentary all through their racial careers, and thus to lack the stimulus to higher development that comes with freedom of movement. Activity and alertness are ever rewarded by a more complex body structure and a more sensitive nervous system, resulting in high mentality.

In the embryos of cœlenterates and other animals, the well known gastrula stage — tiny twirling floaters with a digestive cavity — is very interesting in showing how the various modes of living adopted led directly into the starting of fundamental variations that gave rise to different phyla. Those embryos that went to the sedentary, easy-going life, catching the food that drifted within reach of their mouths,

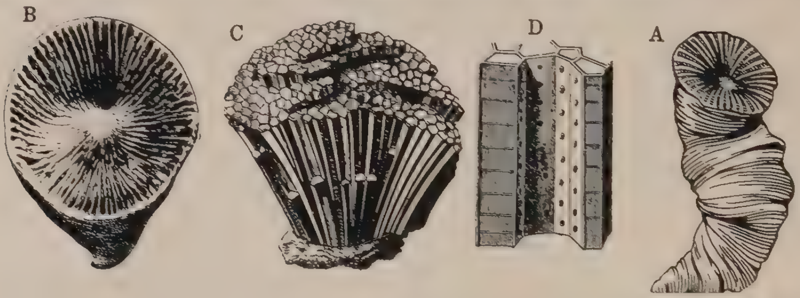


Fig. 22. — Paleozoic "stony" corals. *A* and *B*, individual tetracorals, with the radially arranged partitions in four quadrants; *C* and *D*, compound tabulate corals, with transverse partitions or tabulæ. *D* much enlarged to show tabulæ and communicating mural pores. *A*, *Heliophyllum halli* (Mid. Devonian); *B*, *Zaphrentis umbonata* (Mid. Silurian). After Rominger. *C* and *D*, *Favosites polymorpha* (Mid. Devonian).

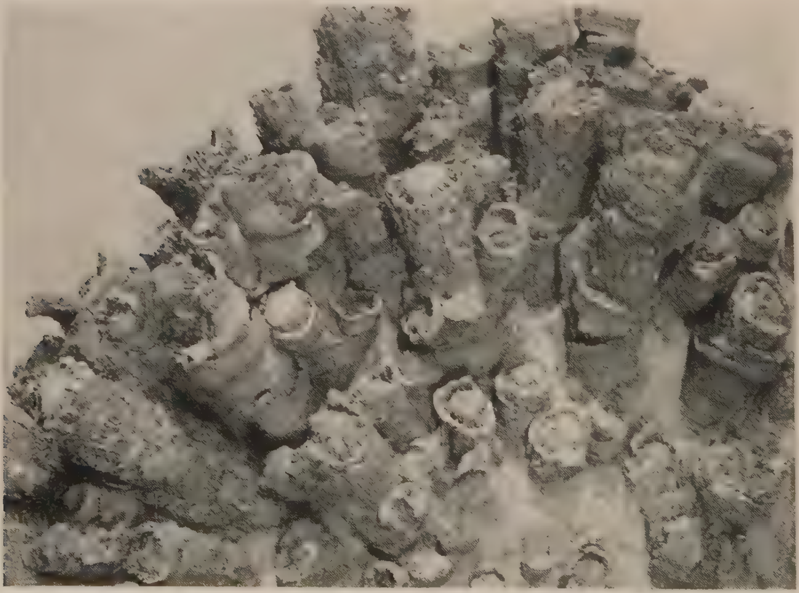


Fig. 23. — A colony of Late Paleozoic cup corals (*Lithostrotion proliferum*), showing many individuals. American Museum of Natural History.

became the home-keeping cœlenterates. Other, more active embryos remained free and hunted their food by gliding or wriggling over the sea bottom; and as a result gave rise to the elongate wormlike type of body that is bilaterally symmetrical. *In this elongate bilateral symmetry lay all the future possibilities of the higher animals.* Due to these marked body pulsations or wrigglings, still other forms started a third line of fundamental structures, giving rise to a segmented body, and these became the very active annelid worms (Phylum Annulata, p. 55). This is a highly progressive stock.

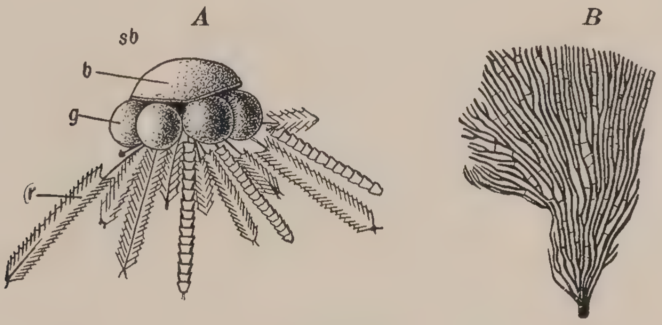


FIG. 24. — Graptolites. *A*, restored colony of floating type (*Diplograptus pristis*). Somewhat enlarged. After Ruedemann. *b*, swimming bell; *g*, gonangia or brooding organs; *r*, a branch (rhabdosome) of many individuals in two ranges. *B*, dendroid type of anchored graptolites (*Dictyonema crassibasale*); the individuals are microscopic and like those in *A*. After Bassler. See also Fig. 60.

Phyla Platyhelminthes and Nemathelminthes. — Worms are commonly thought of as among the lowliest and least attractive of animals, but from an evolutionary standpoint they are of much significance. Representatives of this elongate type of body are the flatworms or ribbon worms (Platyhelminthes) and the roundworms (Nemathelminthes), which move over the sea bottom or bury themselves in it. These are the lower types of wormlike animals.

Phylum Molluscoidea (mollusc-like). — Includes the classes Brachiopoda and Bryozoa.

Brachiopods (Fig. 25) are small marine animals, living between two shells or valves, which suggest those of the molluscs; the animals themselves are, however, related structurally to the worms. Normally they are attached to some other object by the posterior end of the body, which projects from the base of the bivalved shell as a fleshy, tubelike peduncle or stalk. The name, originally given to the group by Cuvier, means " arm-footed," but as a matter of fact the animal has neither arms nor feet, being sedentary, as we have seen, and using its so-called

GEORGE MARK ELLIOTT LIBRARY
The Cincinnati Bible Seminary

"arms" as breathing and food-getting organs. The shells, usually of calcium carbonate, lie on the dorsal (back) and ventral (belly) side of the soft-bodied animal, contrary to those of the bivalve molluscs, which are borne on the right and left sides.

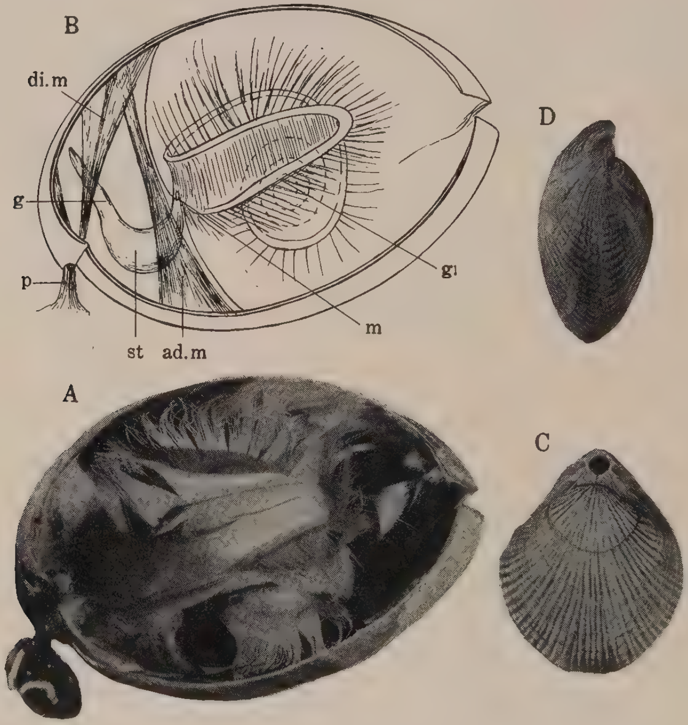


FIG. 25. — Brachiopods. *A*, living brachiopod in the position of growth, the near side cut away to show the relation of animal to shell. The chief structures of the animal are shown semidiagrammatically in *B*. Note that the body (left) is very short, the anterior two-thirds of the shell housing only the coiled and plumose gills (*gi*). The peduncle (*p*) emerges through a foramen at the posterior end of the shell. The mouth (*m*) leads to a simple digestive system indistinctly divisible into stomach (*st*) and gut (*g*). Two sets of long muscles run through the body, the closing ones (*ad. m.*) being opposed by those that open the shell (*di. m.*). *C* and *D*, lateral views of the shell of another living brachiopod, showing the opening for the peduncle and the relation of the two valves. Peabody Museum, Yale University.

More than 200 kinds of living brachiopods are known, but they were especially characteristic of Paleozoic time, when there were 2500 kinds in North America alone. A few of them are among the longest-lived animal stocks known, the genera *Lingula* and *Crania* having persisted through all the physical changes since the Cambrian. Brachiopods are often very important horizon markers in Geology.

The *Bryozoa*, or moss-animals (Fig. 26), are also important in Geology, due to their habit of making reefs. The living ones, growing mainly in the oceans, and from tide-level to over 18,000 feet of depth, are colonial animals, with each individual more or less surrounded by a horny or calcareous wall. Only those with the calcareous walls occur fossil. Certain of them, growing plantlike in beds, form veritable "animal gardens," and, when fossil, thick beds of limestone.

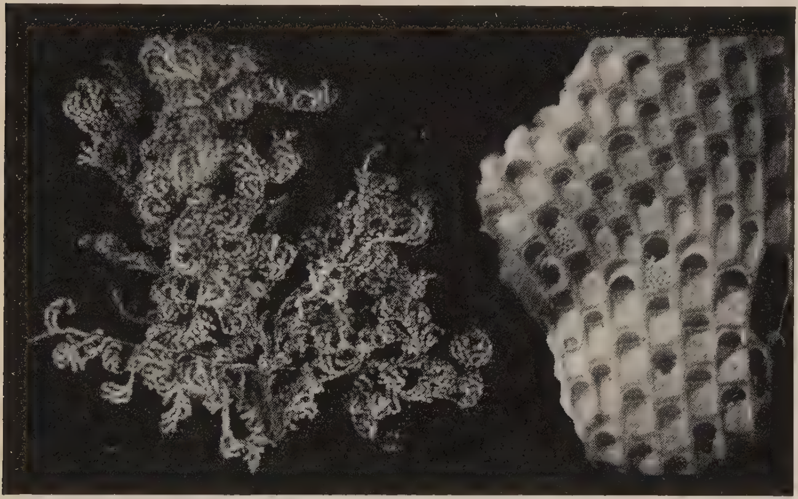


FIG. 26. — Living Bryozoa. At the left, a colony of moss-like form (*Menipea*), and at the right a much enlarged fragment of a lace-like colony (*Schmidtella*), showing the cell-like chambers of the individual animals. Peabody Museum, Yale University.

The phylum Molluscoidea is one of the debatable groups, as to name, content, and genetic position, since the two classes it contains are not structurally alike, and neither of them is related to the molluscs, though the brachiopods resemble certain of the latter superficially.

Phylum Echinodermata (means spiny-skinned, but this condition is present only in the sea-urchins or echinids). — The phylum has two main divisions: (1) forms that are stalked and anchored throughout life or only during its early stages, and (2) free-living forms, free living being a new or re-invented habit of life in this phylum. As adults, all have more or less of the radiate plan of symmetry, well seen in the common starfish.

The sessile or stalked Echinodermata include the Cystoidea, Crinoidea, and Blastoidea, all three of which are common as fossils in Paleozoic rocks. The free forms having fossils are of the classes Asteroidea (starfishes), Ophiuroidea (brittle-stars), and Echinoidea (sea-urchins).

The *cystids* ("bladder-like") and the *blastids* ("bud-like,"see Pl. 15, Figs. 3, 4; Pl. 19, Figs. 6, 7) belong entirely to the fossil world and are of relatively slight importance even there. The *crinids* ("lily-like," see Fig. 67), on the other hand, are still swinging at the ends of their long stalks in the modern oceans, though in no such profusion as in those of the Paleozoic. The ancient crinids were at times exceedingly gregarious, so much so that their fossil remains form great masses of limestone (Fig. 73). The globular body or "calyx" bears a crown of plume-like arms with branchlets (pinnules); in these arms and extending out into the pinnules are food grooves lined with waving cilia, which take the food from the water as it passes by. The anchoring stalk may be long or short or even absent. When at maturity there is no stalk, the animal is either fastened to the ground directly by the calyx, or is free to crawl around on its arms. (Fig. 27.)

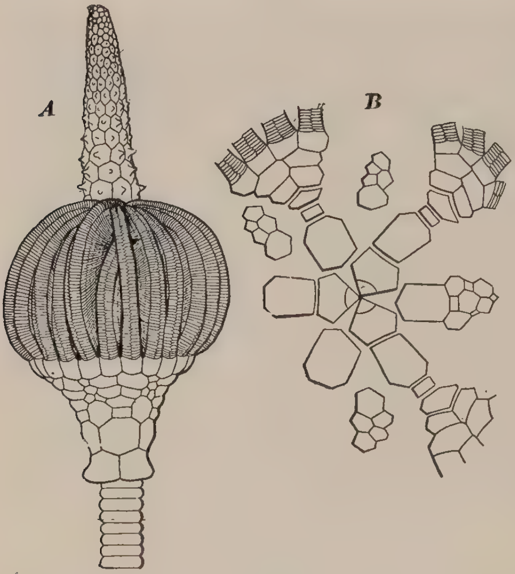


Fig. 27. — A box crinid (*Batocrinus pyriformis*) from the Mississippian of Iowa. *A*, stalk, calyx, arms, and anal tube, from the side. *B*, plates of calyx spread out to show shape and arrangement. After Keyes, Geol. Surv. Missouri. See also Figs. 67 and 73.

The *starfishes* are too familiar to need much discussion. A Paleozoic starfish differed in no general character from the ones now crawling around on our shores. They are rare fossils and of little value as time guides. (Fig. 28.)

Other free-living echinoderms are the *ophiurids*, which are somewhat similar to the starfishes but have slenderer and more fragile arms; and the *echinids* or sea-urchins and sand dollars of our coasts (see Fig. 29). Ophiurids are not of special importance as fossils, but echinids occur in considerable abundance in the Mesozoic.

This phylum shows to-day no signs of decline or extermination, but, like the cœlenterates, it has developed into nothing higher. Apparently the plan of radial symmetry, though efficient enough in these two groups, offered no possibility of further evolution.

Phylum Annulata or Annelids. — The worm-shaped but segmented marine annelids (Fig. 30) must not be confused with the unsegmented lower worms, the platyhelminths and nemathelminths. Because the annelids are soft-bodied, they are very rarely met with as fossils, but occasionally the tube-living forms are common, as are also their burrows made in silts and sands. Annelid tubes are, in fact, among the oldest known fossil records, going back to Proterozoic time (see Fig. 54).

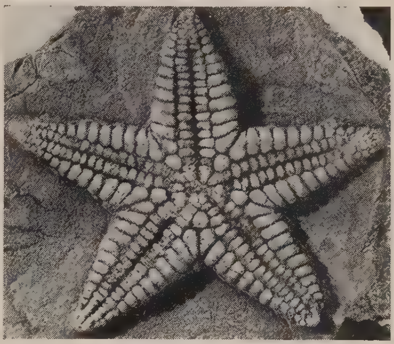


FIG. 28. — Cast of *Devonaster eucharis*, a Paleozoic (Devonian) starfish from New York. Peabody Museum, Yale University.

As we saw a little earlier, the bilaterally symmetrical, wormlike type of body, coupled with an active wriggling habit, held great possibilities for evolution, and it is highly probable that the annelids were in the direct line to the higher animals with their stiffened and segmented axis along the center of the back.

Phylum Mollusca (Lat. *mollis*, soft, referring to the soft bodies). — This is a highly prolific and wonderfully varied stock of shelled invertebrates, most common and differentiated in the seas and oceans, far less so in the fresh waters, but met with in most lands in the shape of the highly variable snails. There are at least three classes of molluscs, the Gastropoda, the Lamellibranchiata, and the Cephalopoda.

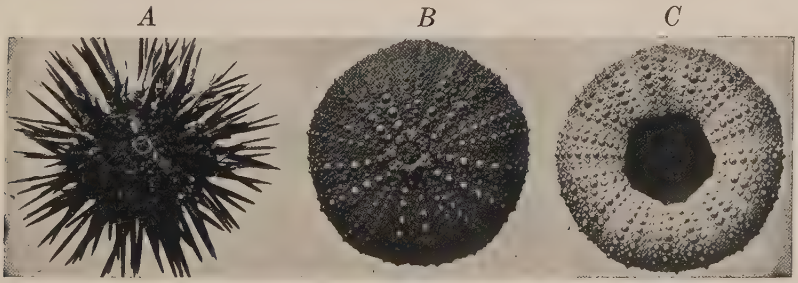


FIG. 29. — Skeletons of two kinds of living sea-urchins (Regularia). *A*, purple sea-urchin (*Arbacia punctulata*), with all its spines, from dorsal side, × 1/2. *B*, *C*, common sea-urchin (*Strongylocentrotus dröbachiensis*), stripped of its spines to show shell from dorsal and ventral (mouth) sides, × 1/2. After Coe.

The *gastropods* (Fig. 31) are single-shelled molluscs such as the modern limpets, drills, periwinkles, whelks, snails, etc. They live under all conditions, in the seas, in the fresh waters, and on the dry lands, the world over. The usual form of the shell is a spirally twisted cone with the apex upward, and because of this single shell they are called univalves, in contradistinction to the brachiopods and the lamellibranchs, which have two shells and are therefore bivalved. From the bottom of the shell, which can be closed by a cover or operculum, the fleshy head and foot protrude when the animal is feeding or crawling; it is this ventral mode of locomotion that gives them their name, which means belly-footed. Primitive forms of gastropods were present in the Cambrian, and the group has continued to the present time, the number of living species running over 20,000.

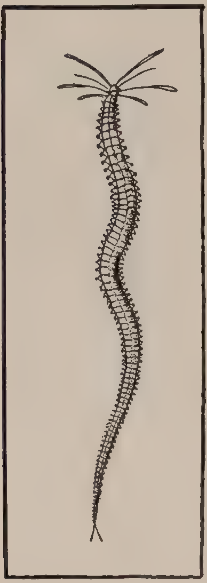


Fig. 30. — *Nereis*, one of the common marine worms, or annelids, of to-day. Similar ones lived as far back as the Proterozoic era. See Fig. 54 and Pl. 11, Figs. 1–3.

Another group of molluscs, the degenerate, bivalved *lamellibranchs*, the tribe to which the clams and oysters belong, dates back to Ordovician time. When first born, these creatures even to-day have a head with eyes, but soon lose both on encasing themselves in their two shells. The shells, one on the right and one on the left side, are joined and hinged along the animal's back by an elastic ligament which tends to hold them agape below, to allow the inflow of water. They are closed by muscles that run transversely through the body. The animals are nearly always free, and live chiefly in the oceans, but also in the fresh waters. As the name indicates, they have plate-like or lamellar gills, used as breathing organs and as food-catchers, which bring currents of water into the shells and strain out of it the microscopic food and oxygen. Hence all they need to do in order to maintain themselves is to open their mouths, stir the water a little, and strain the food particles out of it. In consequence of their marked degeneracy their chief rôle in the economy of Nature has ever been to furnish an abundant supply of food for many kinds of animals from starfishes to man. (Fig. 32.)

In strong contrast to the extreme sluggishness and low mentality of the gastropods and lamellibranchs, the *cephalopods* show an alertness that makes them conspicuous among their associates. They are of two general types, shelled and shell-less. The shelled cephalopods are in turn divisible into two great groups, the *nautilids*, beginning in the Early Paleozoic and continuing to the present time, and the more complex *ammonites*, which lived from the Late Paleozoic through the Mesozoic.

The shelled cephalopods, starting in the early part of the Paleozoic with a straight and chambered shell (Fig. 61), soon began to bend it until it became coiled like a watchspring (see Fig. 33), as it is in the living nautilus. This coiled shell is divided transversely by partitions (septa) into a series of compartments between which connection is maintained by a siphon that passes through perforations in the septa. The shell is built as the animal grows, and the latter lives always in the forward compartment, shutting off the empty ones behind. The unoccupied chambers are filled by gas supplied by the siphon and apparently help support the weight of the shell in the water. The foot in this group has become transformed into a crown of tentacles around the mouth (the name means head-footed), which are used for grasping prey and are also applied to stationary objects in order to hold the animal while at rest or to pull it along when crawling. Cephalopods are, however, active swimmers, having a special funnel-shaped organ through which the water is jetted, driving the animal backward.

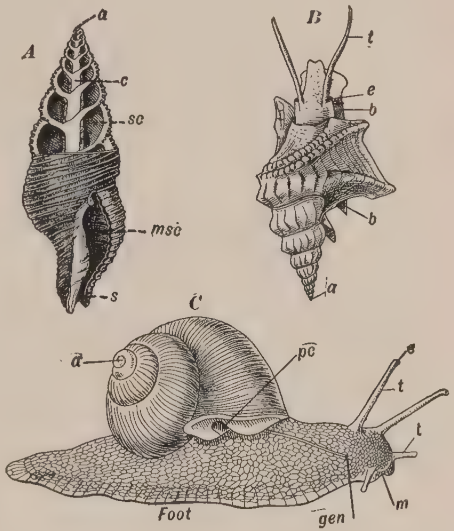


Fig. 31. — Gastropods. *A*, regular marine gastropod (*Latirus*), with the spiral shell wound to the right (dextral). After Steinmann. *B*, another marine gastropod (*Aporrhais*), with the animal crawling. After B. B. Woodward. *C*, an air-breathing (pulmonate) land snail in the act of crawling, the head with pairs of sensory tentacles, the long ones bearing eyes. After Hatschek and Cori. *a*, apex of shell; *b*, foot; *c*, interior columella; *e*, eye; *gen*, genital opening; *m*, mouth; *msc*, mouth of shell cavity; *pc*, opening into pulmonary cavity; *s*, siphonal cavity; *sc*, interior shell cavity; *t*, sensory tentacles.

In one stock of straight-shelled cephalopods, the animals, as it were, made their way more and more out of the external shells and enveloped these in such a manner that they became internal skeletons. These were the *belemnites*, out of which came our modern cuttle-fishes and squids.

Phylum Arthropoda (means having jointed limbs). — This is the grandest phylum for differentiation and number of species in the Kingdom Animalia. The stock arose in the segmented and bilaterally symmetrical annelid worms, which developed their rudimentary feet into highly organized jointed walking legs. In the arthropods the organs of sight, smell, taste, and touch are for the first time well developed. There are five great classes and four of these are of much interest to us.

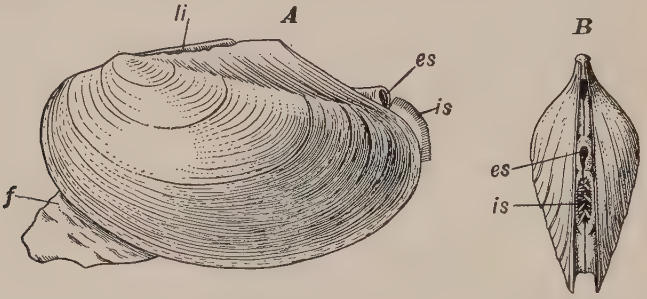


FIG. 32. — A fresh-water lamellibranch (*Anodonta*). *A*, animal as seen from the left side. *B*, from the posterior end. After Howes. *es*, exhalant siphon; *f*, digging and crawling foot; *is*, inhalant siphon; *li*, ligament that opens valves.

The *Crustacea*, or crust-bearers, are so called because they wear an outer skeleton made of a horny substance known as chitin and stiffened with calcium carbonate. In the living world they are the familiar shrimps, crayfish, lobsters, and crabs. The majority of them are marine, though many occur in fresh water and a few, like the rolled-up "sow-bugs" (which are not bugs) and the tropical crabs, have taken to the land for a dwelling place. Still simpler forms of crustaceans are the less well known fairy shrimps and water-fleas of ponds and streams,

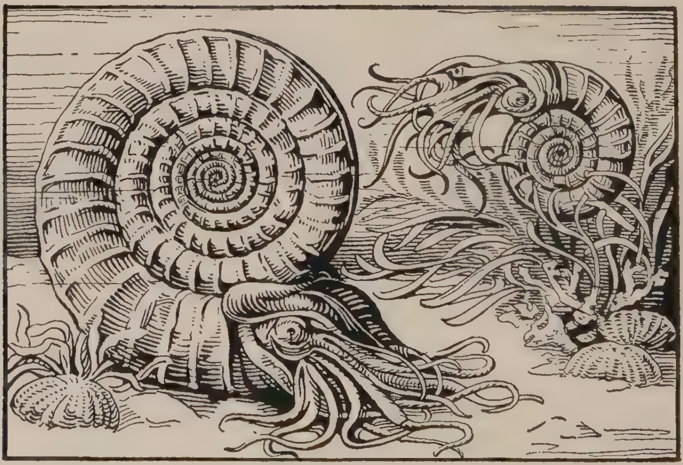


FIG. 33. — Ammonite, with the animal restored. After Fraas, from Schuchert and LeVene's *The Earth and its Rhythms* (Appleton).

and the tiny ostracods, copepods, and cirripeds that form part of the abundant food supply in the oceans.

Of very special interest in geologic history are the extinct members of the Crustacea known as *trilobites* (Fig. 34), which were the first fossils to attract the attention of naturalists. As the name indicates, the creatures are three-lobed, that is, have three divisions that run lengthwise of the body. The transverse segments making up the body are also conspicuous, and are grouped into head, thorax, and tail. The under or ventral side carries rows of double limbs. One branch of each limb was used for crawling and the other for catching food, swimming, and possibly for breathing. The rounded head is relatively large and on the upper or dorsal side bears eyes similar to those of a fly, composed in some forms of an enormous number of lenses (30,000). The trilobites varied in size from 0.4 of an inch to 28 inches, but the average was about 1.5 inches. They were sluggish swimmers, but as a rule preda-

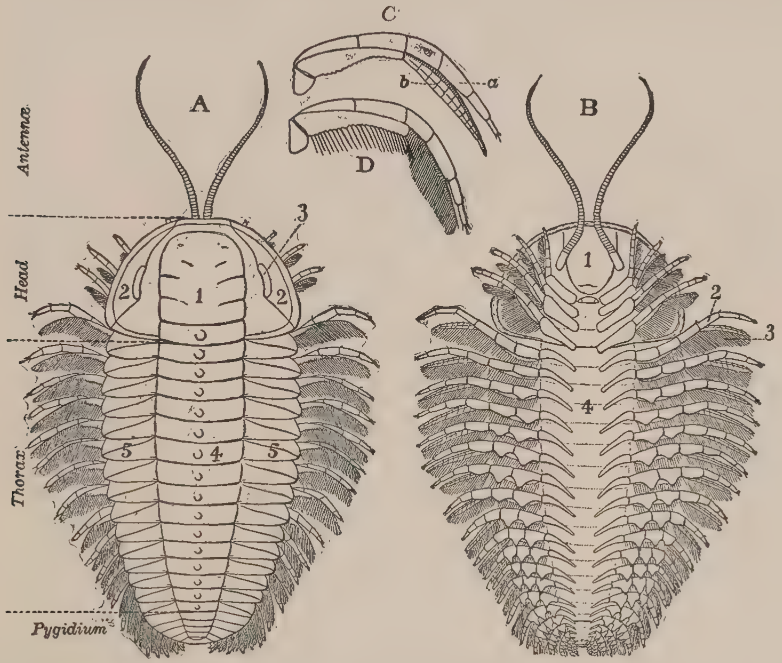


FIG. 34. — Sketches of a complete trilobite (*Triarthrus becki*). × 2. After Beecher. *A*, dorsal or upper side of carapace, showing three lobes, pleura (5), rachis or axis (4), glabella (1), and free cheeks (2) which bear the eyes (3). *B*, ventral or under side, showing double or biramous limbs (2, 3) attached to rachis (4), and upper lip or hypostoma (1) which covers mouth. *C*, one of the double legs, seen from above, stripped of setæ or food-catching organs. *D*, another leg with setæ attached; the upper member of the leg is for food-catching and swimming and the lower part for crawling.

tory, representing the ever-present carnivorous element in the faunas of the Early Paleozoic until they, too, fell victim to the stronger cephalopods and fishes.

Arthropod groups of lesser importance as fossils are the *Arachnida* or spiders, and the *Myriapoda* or many-legged centipeds and galley-worms. Both are of moment historically, however, in that they were among the very first of the invertebrates to come out of the seas and live upon the lands. (Fig. 35.)

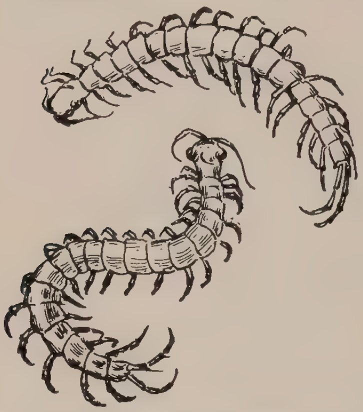


Fig. 35. — Centipeds, representative of the Myriapoda, one of the first groups to try living on land.

Of greatest significance in the living world are the insects (*Insecta*), often called Hexapoda on account of their six legs. From the point of view of numbers and diversity they form, indeed, man's only rival for world supremacy. They took to growing wings almost from the start of their history — and their lineage is ancient, going back at least to Pennsylvanian time. At first they had two pairs of wings, which could not be folded back over the body but stood out stiffly when at rest, as in the dragon-flies or mosquito-hawks; the later types, however, have folded wings, and in the flies the number has been reduced to two.

Insects have a thin external chitinous covering, like all of the arthropods, and breathe air through respiratory tubes (tracheæ); they live and rear their young on and below the ground, in fresh and marine waters, in dead or living plants and animals, and as parasites on much other life and even on each other; and the flying kinds are much in the air. Some also lead a communal life (ants, termites, bees), with the individuals modified for special kinds of labor — a condition seen nowhere else. Some are highly phosphorescent, as the fireflies, and most insects see very well with their compound eyes. In general, the insects have adapted themselves to more kinds of food and environment than any other stock of animals. Some develop directly from egg to maturity, but the majority pass through a more or less complicated wingless larval life that may be short or prolonged through several years, finally reaching maturity after a series of moults; in others there is complete metamorphosis in that the feeding larvæ pass into a quiescent pupal stage in which no food is eaten, and then are transformed into the imago or adult form.

There are twenty orders of living insects, and all but two of the major groups can be traced back to the Jurassic with little essential modification. Mayflies, dragon-flies, scorpion-flies, cockroaches, and other orders were present in the early Permian, along with forms ancestral to still other groups (Fig. 83). The first known fossil insects are Pennsylvanian in age, but they probably originated at least as early as Devonian time.

Among the land-living invertebrates, the insects have the highest intelligence. Of all animal types it is they alone that compete with man for the possession of the land (Rohwer thinks there may be five million kinds of living insects), but the reasoning and destructive powers of man will in all probability keep them in subjection. On the other hand, if man should vanish, it might well be that the world of insects would rise into dominance of the land habitats.

VERTEBRATES OR CHORDATES

The phylum *Chordata* includes the most complex and most intelligent organizations of all life, and was the last of the phyla to originate. All the members of the phylum possess, at some stage in their life history, three characteristics that are found in no other phylum: (1) the anterior portion of the alimentary canal is in communication with the outside by a series of gill-slits or clefts (best seen in the fishes); (2) there is developed as an outgrowth from the dorsal wall of the alimentary canal a rod of tissue (notochord) which is the foundation of the backbone or axial portion of the skeletal system of the body; (3) there is a central nervous system lying exclusively on the dorsal side of the alimentary canal. (Fig. 36.)

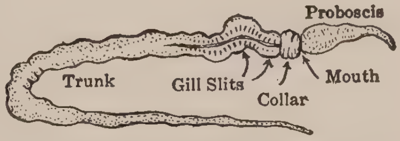


FIG. 36. — The hemichordate *Balanoglossus*, a wormlike form living in the mud or sand of the seashore, but possessing gill-slits, a notochord, and a central nervous system above the alimentary canal.

The three more primitive subphyla of chordates (Hemichordata, Urochordata, and Cephalochordata = lancelets) are hardly ever seen as fossils, but the subphylum Vertebrata is abundantly present. These last are the true backboned animals of oceans and lands, with a skull and two pairs of jointed limbs. The vertebrates are divided as follows:

Class Pisces or Fishes (Fig. 37). — This is the first markedly successful class of vertebrates. They are as well adapted to the water as the birds are to the air. Their body temperature is about that of the water in which they live, wherefore they are said to be cold-blooded, and they have gills on each side of the head for oxygenating the blood. Their principal organ of locomotion is the powerful tail fin. This is assisted by paired fins, of which the forward pair are known as the pectoral fins and the rear ones as the pelvic fins. It is out of these fins, or limbs, that the fore and hind legs of the higher vertebrates arise. An air-bladder is generally present; this may serve as a float, but in certain forms has been modified into a cellular sac which acts as a lung and assists the gills in respiration. As will be shown later, it is this cellular sac that has the possibility of modification into lungs in the amphibians.

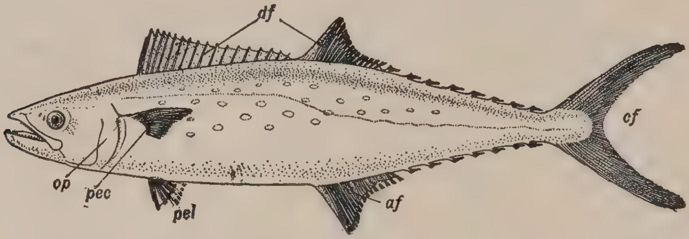


Fig. 37. — Spanish mackerel, a swift-swimming fish, to show external parts. After Goode. *af*, median anal fin; *cf*, caudal or tail fin; *df*, dorsal median fins; *op*, left operculum or movable covering over gills; *pec*, one of the front paired or pectoral fins; *pel*, paired pelvic fins, which may in different fishes be situated anywhere from this position back to a place in front of the anal fin.

Class Amphibia. — Frogs, newts, sirens, mud-puppies, and land salamanders are types of living amphibians (Fig. 38). They are cold-blooded like the fishes, and are nearly all tied to an aquatic environment, in that they have to lay their eggs and pass through the "tadpole" stage in the water, though they may during the rest of their life rarely return to it. The class name Amphibia, in fact, which means *living a double life*, refers to this habit of living both on the land and in the fresh waters. Some of them, however, live entirely in the water.

All Amphibia in their youth are provided with two or three pairs of external gills, or internal ones with external gill-clefts. The former are soft feathery outgrowths situated at the back part of the head and rich in bloodvessels (see Pl. 22, Fig. 2). Such gills are also present in the lung-fishes, and in the sirens and mud-puppies they may persist throughout life, though this condition is rather exceptional. In the salamanders of the land, and in all of the tailless Amphibia (frogs, etc.), the gills disappear and adult respiration is carried on wholly by lungs, as in the higher vertebrates. While the gills are vanishing, the anterior gill-slit is transformed into the eustachian tube, which is closed externally by the ear drum (the latter is also present in fishes); and thus have arisen the ears of all higher vertebrates.

Class Reptilia. — In the vertebrates so far studied — fishes and amphibians — we have seen that the habitat is either wholly in the water, or that at the very least the small eggs are there laid and fertilized, and that the young are also born and spend the days of their youth in this element. All of the higher vertebrates remove themselves more and more from this habitat, and none are developed in it directly from the egg. In other words, the reptiles, as a rule, lay large eggs which, like those of birds, are provided with a more or less great quantity of food (yolk), and are fertilized before they are laid upon the land to hatch. This is the most important and fundamental difference between the lower vertebrates, the fishes and amphibians, on the one hand, and the higher vertebrates, the reptiles, birds, and mammals, on the other. Some reptiles, however, produce living young and are therefore viviparous.

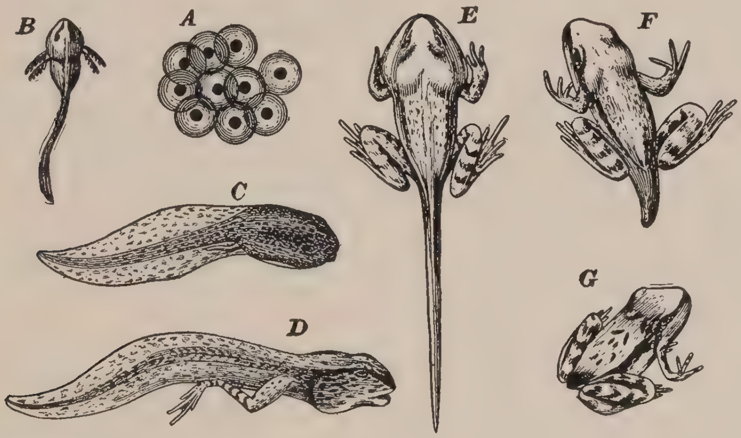


FIG. 38. — Development of the frog (*Rana temporaria*). *A*, eggs, greatly enlarged; *B*, tadpole or polliwog, with two pairs of gills; *C*, tadpole with first indication of hind legs; *D*, older tadpole; *E*, tadpole with both pairs of legs free; *F*, *G*, stages in which the tail is resorbed. Redrawn from Leuckart's wall charts.

All of the living animals known as turtles and tortoises, lizards and snakes, alligators and crocodiles, belong to the class Reptilia. The word reptile means *creeping* or *crawling*, and has reference to an animal that goes on its belly like the snake, or moves with difficulty on short sprawling legs, like the alligator. There are, however, many reptiles that are in no sense creeping and crawling animals, as, for instance, many of the sprawling but fleet-footed lizards, certain of the medieval dinosaurs with their pillar-like legs, and the winged pterodactyls.

All living reptiles are cold-blooded animals like the two lower classes of vertebrates, and their skin is never soft but always more or less hardened by horny or bony material that occurs more often as scales than as armor plate. Each animal has a pair of lungs, but in the elongated snakes the left lung is rudimentary and almost lost.

In the snakes and in some lizards, legs are either wholly absent or are represented by mere vestiges buried in the flesh.

The paleontologist knows at least fourteen orders of reptiles, and there may be nineteen, but of all this vast array only four orders have living representatives. These are the turtles, the snakes and lizards, the crocodiles and alligators, and the little known *Sphenodon* of New Zealand, a relic of Permian times. Among these extinct orders of reptiles none are more wonderful than the dinosaurs, rulers of the medieval lands, to which Chapter XVI is mainly devoted.

Class Aves or Birds. — Flying, running, wading, and swimming vertebrates with feathers. The medieval forms had many teeth of reptilian type.

Class Mammalia. — Mammals, structurally the highest group of animals, are warm-blooded vertebrates with milk glands. These are the mammary glands or breasts, the structures from which the class has taken its name, for *mamma* means *breast.* All mammals are more or less covered with hair, which is as characteristic of them as feathers are of birds. The body cavity differs from that of all other vertebrates in that it is completely divided into two parts by a muscular membrane, the diaphragm, which separates it into a thoracic cavity containing the heart and lungs, and an abdominal cavity containing the remaining viscera. In most mammals there are two sets of teeth, the milk dentition or temporary teeth which eventually fall out, and the permanent teeth which succeed them. The heart is four-chambered as in the other class of warm-blooded animals, the birds, and the course of the blood through it is the same in both.

The brain in mammals attains the highest degree of development known, reaching its greatest perfection in man.

Most mammals have a completely terrestrial habitat, while the seals, sea-lions, sea-cows, whales and porpoises live in the oceans. One order of wide distribution, the bats, has developed the front limbs into wings, while other stocks have lateral or body membranes between the limbs, and spreading these, glide from tree to tree.

The most primitive mammals were the monotremes, which were egg-layers like the majority of the reptiles. The next advance is represented by the marsupials, such as the kangaroo, whose young are born imperfectly developed and carried in a pouch in the mother's body until they can take care of themselves. The great horde of living and fossil mammals belong to the group Placentalia, the placenta being a special growth, partly of fœtal and partly of maternal origin, in which the young during the period of gestation are developed to greater perfection.

CHAPTER VII

THE EARTH BEFORE GEOLOGIC TIME

The science of Geology is bounded on the one side by Astronomy, and on the other by Biology; it begins in Astronomy, and, aided by cross-fertilization from Chemistry and Physics, learns how to interpret the rocks with their entombed life, thus preparing the way through Paleontology for an understanding of the living world. Of these sciences none is grander in its study of space and time, and all that these dimensions imply in philosophy and religion, than Astronomy; none so grand as Geology for Earth phenomena and the unfolding of life.

The Universe Around Us

Cosmogony, which seeks to explain the creation of the Universe, came into being as an actual science in 1610, when Galileo turned his home-made telescope on the Milky Way and proved it to be nothing more than " a swarm of faint stars scattered like golden dust on the black background of the sky." So says Sir James Jeans in his recent book (1929) which bears the title placed at the head of this section. From that time to this, astronomers the world over have been searching the heavens with telescopes of increasing efficiency, and it is their accumulated discoveries upon which we shall draw for the following facts.

The *Universe*, of which the Earth is so infinitesimal a part, is made up of an untold number of spiral masses (white nebulæ) composed of stars and of the gaseous material out of which stars are made (Fig. 39). Of such nebulæ two million are estimated to be visible in the largest telescopes. Our own star aggregate, known as the *galactic system or galaxy*, is one of these spiral masses, and has the general shape of a watch or lens, with a diameter of 200,000 light-years (a light-year being the distance light travels in a year, moving at the rate of 186,000 miles per second). The greatest number of stars by far in our galaxy are in the Milky Way. For a long time, the Sun was supposed to be near the center of the galactic system, but the most recent researches place the center 47,000 light-years away from it Nevertheless, if not the actual center of the galaxy, the Sun is the center of our own special part of it, the *solar system*, being the star nearest to us of the possible 300,000 million in the galaxy. More than this, it is one of the two " parents " whose influence upon one another led, as we shall see, to the birth of the planets in the solar system, and so it has a very great interest for us.

Despite its mass of 332,000 times that of the Earth, the *Sun* is a so-called " dwarf star," with a diameter of but 865,000 miles as compared with the 216–390 million miles of the four largest stars measured. It is a gaseous body which has been cooling down through the greater part of its history, and yet it has a surface temperature of about 6000° C. or nearly twice that of the hottest part of the electric arc; at the center, its temperature is estimated as around 40 million degrees. This matter

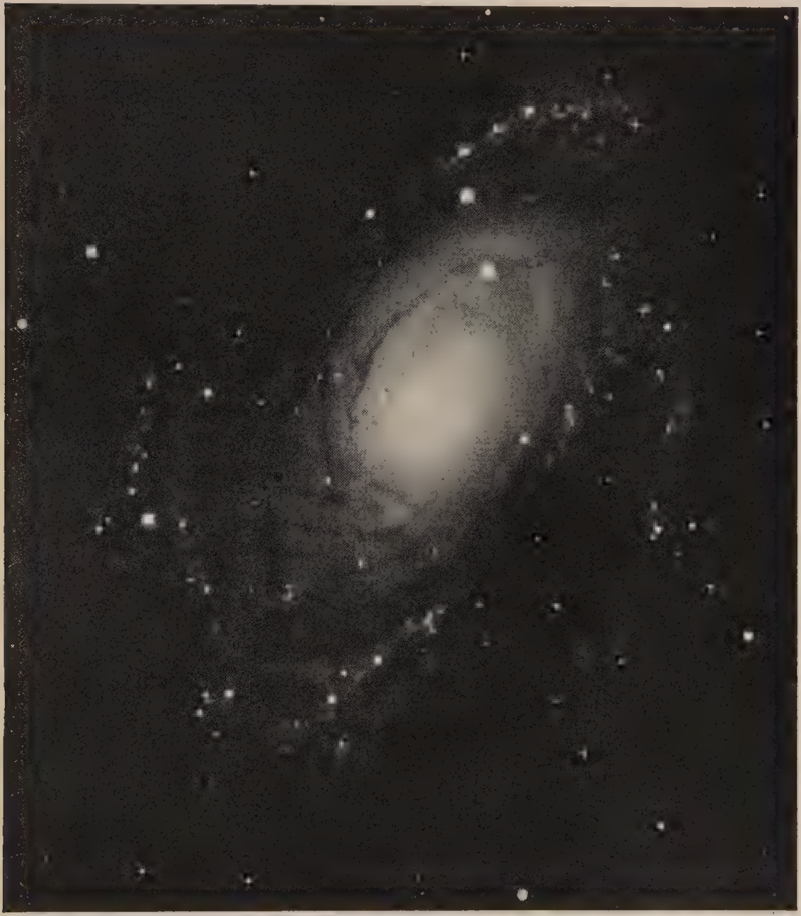


FIG. 39. — The spiral nebula *M* 81 in Ursa Major. Photographed by Mt. Wilson Observatory, with 60-inch reflector, and an exposure of 4 hours and 15 minutes, February 5, 1910.

of the Sun's temperature is of the greatest possible import to us, since from this source come all the light and heat that have made the Earth a possible abode of life in the past and still keep it so.

Around the Sun swing in their respective orbits the nine known planets (including Pluto, discovered in 1930), the more than a thousand tiny planet-like asteroids lying between Jupiter and Mars, and the unknown number of comets. The asteroids represent probably "the broken fragments of a primeval planet," but it is the origin of the planets, as typified by the Earth, that is to interest us for the remainder of this chapter.

Origin of the Earth in Cosmic Time

Geologists always have before them in their deciphering of Earth history the knowledge of an external shell of rock; the farther back they go into this history, the more obscure the knowledge becomes, but there still remains an Earth differing from the present one mainly in having a different sort of atmosphere and in apparently being devoid of all life.

As material and forces are everlasting, however, there must be an Earth history back of what the geologist discerns in the rocks, and in an attempt to ascertain these earlier stages he must seek the aid of the sciences of Astronomy, Physics, and Chemistry. The starry heavens as seen by the astronomers through their wonderful instruments reveal this probable history, and it is this knowledge as interpreted by geologists, physicists, and chemists that is now to be described in general terms.

Nebular Theory of Kant and Laplace. — Astronomy and Physics received a great impetus from Newton's principle of universal gravitation, given to the world in 1687, a principle that led to a sound conception of the evolution of the solar system. This Newtonian law was the basis of Immanuel Kant's nebular hypothesis, which that professor of mathematics and physical geography at Königsberg presented in 1755. Kant conceived that the Universe, as then understood, must have been developed out of chaos and that space was filled with highly attenuated fundamental material, locally varied as to mass, density, and attraction. In time this material segregated into spinning masses of highly attenuated gas, or nebulæ, which gave rise to hot stars, of which the Sun is one. He further imagined the solar nebula, or ancestral Sun, to have given rise to the planets.

This conception of Kant was modified by the French astronomer Laplace, who in 1796 and again in 1824 proposed what has become known as the "nebular hypothesis" of Earth origin. It was the first serious scientific cosmogony, developed in detail with a mathematical precision quite beyond the capacity of Kant (Jeans). Laplace thought that our ancestral Sun, long before it gave birth to its family of four outer large planets and four inner smaller ones, was originally in a state of luminous vapor, extending even beyond the orbit of the vastly remote planet Neptune. This ancestral Sun he pictured as a rotating nebula of gas that was slowly contracting through loss of heat by radiation, and leaving behind, one after another, in the course of a long time, nine rings of gas liberated from the equatorial region of its mass; these gaseous rings in turn condensed into the nine planets and the many and much smaller asteroids. In the same way the planets in turn cast off their satellites or moons. However, astronomers now say that such tenuous gaseous rings, rotating as if they were solids, are unthinkable, and that no nebula is known closely resembling the one that supposedly gave rise to the solar system. They furthermore believe it to be impossible for such gaseous rings to draw together into planets.

Planetesimal or Cold-earth Theory of Chamberlin and Moulton. — Nearly all the hypotheses as to the origin of the stars and Sun derive them from an antecedent gaseous nebula. As far back as 1750 Buffon of France had suggested that the solar system might have been produced through the grazing impact of a comet, but Laplace thought little of the idea. The theory was revived in 1880 by Bickerton, who replaced the intruding comet by a star, and introduced the notion of a "third body," a nebula surrounding the Sun and formed by the impact, out of which were evolved the planets. The idea that the solar system was of biparental origin was, however, first worked out scientifically by Chamberlin and Moulton in 1901 and subsequent years. This theory holds that the gaseous Sun either approached, or was approached by, another and probably a larger star, and that due to the mutual attraction tidal action was set up, partially disrupting the Sun (see Fig. 40). The hot gaseous material so drawn out from the Sun took on the form of two vastly long spiral arms connected with the central body, but the mass in the arms was after all but a minimal part of the Sun. The drawn-out gases, according to the authors of the theory, cooled quickly into dustlike material, which they called *planetesimals*. Included in this cold dustlike material were many relatively large and probably internally hot masses, called knots, and these, attracting to themselves the planetesimals, built up the nine planets, their twenty-six moons, and the many asteroids. This stage in the evolution of the solar system is believed to have endured through an immensely long time.

Planetoidal or Hot-earth Theory of Barrell. — The long-drawn-out formative time postulated by the planetesimal theory is meeting with criticism, and this part of the hypothesis will, it appears, in the course of time be modified. Chamberlin conceives the Earth to have been built up as a solid body out of the cold planetesimals, not to have been fluid or viscous at any time later than the early nuclear stage. Barrell (1918), on the other hand, viewing the probable size of the planetesimals as equivalent to that of the asteroids (up to 485 miles in diameter), inclined to the idea of rapid infall of these larger bodies, which he calls *planetoids*, upon the Earth nucleus. Accordingly, but little time would be consumed during the growth stages of the Earth, and the infall of the planetoids would lead to the formation of a hot earth with a fluid surface. In this, Barrell's theory agrees well with that of Jeans, described below.

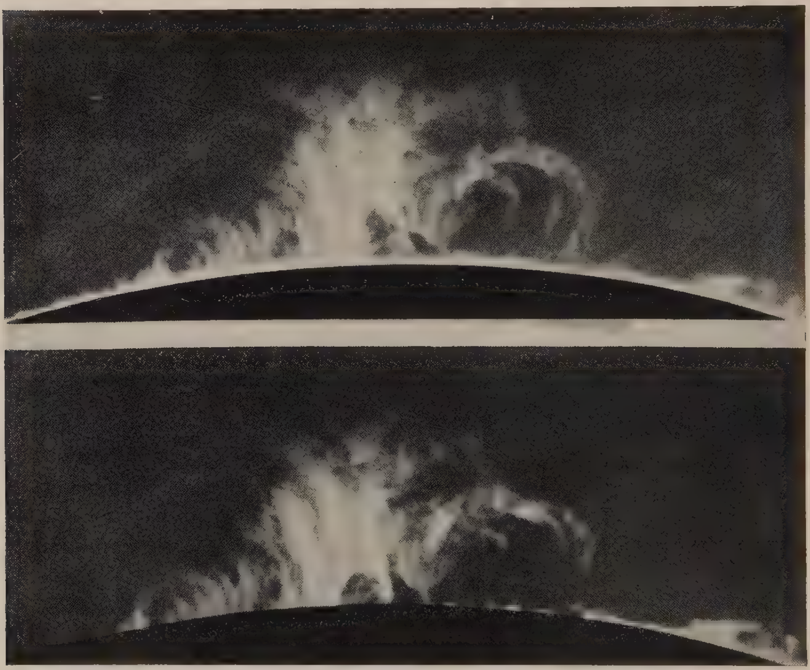


Fig. 40. — Calcium spectroheliograms of solar prominences on October 10, 1910, thrown out to a height of over 60,000 miles. Photograph by Frederick Slocum, Van Vleck Observatory, Wesleyan University.

It can not be known, of course, whether during Earth growth the center, or material of the original knot, tended toward a liquid or a solid state. The outer part of the Earth, however, with a thickness of perhaps the outer quarter of its radius, comprising about one-half the volume of the sphere, seems to have passed into a truly molten condition.

After a long time, the rapid generation of heat by impact of the planetoids lessened, and the fluid sphere, seething with slow convection currents, began to cool. The heavy basic crystals were the first to form, and because of their high specific gravity they sank downward in the convective movement. The remaining higher magma was more siliceous, of lighter gravity, and in crystallization gave to the crust a greater proportion of feldspar and quartz. *The original crust of the Earth was in consequence one of granite.*

The Tidal or Hot Gaseous Theory of Jeans. — The tidal theory of Jeans, fully elaborated in 1916, begins with the biparental idea, as does the planetesimal hypothesis, which is also a " tidal theory." Starting out alike, the theories soon differ, in that, for Jeans, the long arm or arms of matter pulled out of the Sun consist of a hot gas in which the larger condensations grow into gaseous or liquid planets, while the smaller masses are dissipated; whereas for Chamberlin and Moulton the material in the arm or arms cools quickly into a cold dust, in which are more or less large, internally hot knots or attracting centers which very slowly gather in the dust or planetesimals and so grow into the planets and satellites.

Actual collisions between stars, Jeans thinks, must be exceedingly rare, but about 2000 million years ago two stars did come close enough together so that the tides thus set up gave rise to the solar system. Gradually the bigger star receded until its gravitational effect became negligible, and the planets were left describing orbits around the smaller star alone.

Mercury and Venus are thought to have probably become liquid or solid immediately after their birth, the Earth and Neptune were partly liquid and partly gaseous, and Mars, Jupiter, Saturn, and Uranus were " born gaseous and remained gaseous," at least until after the birth of their families of satellites.

The birth of the satellites was also probably due to tidal action. The planets, after their origin, at once began to cool down, the larger ones more slowly, the smaller ones more rapidly. During the earliest stages, their orbits around the parent Sun were still somewhat erratic, and they may have passed near enough to it to start a second series of tidal eruptions in which the Sun took the part originally played by the passing star and the planets played that formerly taken by the Sun. Long filaments of matter were torn from the planets, and out of these their satellites condensed.

The Dark Ages of Earth History (Azoic Era)

According to Jeans, the Earth, as born out of the Sun, was originally a globe of intensely hot gas, but it cooled gradually, becoming first liquid, then plastic. Finally, its outer crust solidified. Vapor condensed into water, and the rivers and oceans came into being. The gases that did not liquefy remained to form an atmosphere. With the formation of the outer rocky shell or lithosphere, the Cosmic era in the Earth's history comes to an end, and geologic time begins. However, no one has yet consciously seen the smallest part of this original crust, nor has Geology discovered the oldest rocks that lie upon it. Therefore a time must be postulated to bridge the interval between the Cosmic events and the known Archeozoic era. This has been called the *Azoic or lifeless era.* During this time the various melts of the crust differentiated into rising masses of lighter rocks (granite) which eventually became protuberant continents, and greater sinking areas with heavier materials (the basalts of the substratum) which gradually became the oceanic basins; a similar differentiation takes place in an iron furnace, when the slag rises to the top and the heavier molten iron stays below. These basins gathered the waters as they finally condensed out of the cooling original atmosphere made up of the gases that had escaped from the molten Earth. With decreasing heat came the cooled rains and the first weathering influences, the making of sediments, and finally their gathering as strata in the seas and oceans.

Primordial Atmosphere. — Granting the initial fluid state of the Earth, there must have been at first a hot gaseous atmosphere consisting chiefly of water vapor, lesser amounts of carbon dioxide and carbon monoxide, chlorine and hydrochloric acid, some nitrogen but possibly no free oxygen. This atmosphere and the Earth's waters (= hydrosphere) are considered as essentially of volcanic origin, being the accumulated exhalations of active volcanoes and thermal springs. The gases are conceived of as dissolved in highly compressed, molten magmas deep within the Earth, which, when the pressure is relieved, finally escape into the atmosphere. (See pp. 212–214 of Part I.)

Gathering of the Ocean Waters. — When the crust began to cool, crystallization went forward in various areas, convection was slowed, and finally the molten rock froze to solidity. Then rain, ever descending from the cloud mantling the Earth, finally attained the lithosphere, which was still very hot. A steaming Earth's surface was of short duration, perhaps only a few thousand years. Then the surface began to assemble an ocean of acid water, probably universal over the lithosphere.

Carbon dioxide became the dominant gas in the rare atmosphere, and water vapor was present in subordinate amounts. Solar heat began to play the principal part in warming the Earth through the now thin and broken cloud canopy. For the first time sunlight attained the surface of the lithosphere.

Volcanic activity was still very great and great volumes of gases were liberated, adding " juvenile " water to the old or " vadose " water of the hydrosphere, a process that still continues. We may, therefore, say that the body of the Earth has given forth its oceans.

Origin of Continents and Oceanic Basins. — Most geologists hold that the fluid Earth originally had a surface as level as that of the ocean. The problem of the origin of the ocean basins and of the continental platforms is a highly speculative one and is connected with that of the nature of the Earth's interior, which is discussed in Chapter II of the first part of this text-book. If the Earth were uniform in character throughout, it is thought that the lithosphere would be quite smooth. In reality, however, the rocks differ from region to region in composition, density, and weight, basalt and other dark-colored igneous rocks being appreciably heavier than granite. It is well known that the rocks underlying the oceans are in general somewhat heavier than those composing the continents, and investigations indicate that the great mountain ranges of the Earth are composed of or underlain by material that is slightly deficient in density or weight compared with the crust as a whole. Expressed in another way, the heavier basic and ultrabasic rocks underlying the oceans consist dominantly of *si*lica and *ma*gnesia, and are hence called *sima*, while those of the lighter protuberant continents are mainly granite and therefore richer in *si*lica and *al*umina (= *sial*). The larger surface irregularities of the Earth's surface are not, therefore, haphazard, but trace back to the fundamental law that differences in surface elevation must be compensated by differences in rock density. Accordingly, as the Earth is composed of heterogeneous materials with different densities, the heavier oceanic basins must lie lower to " balance " (isostasy) the higher-standing, lighter continents. This relation of density differences was established early in the history of the Earth and it has been maintained or even accentuated throughout the geological ages, with the added fact that the periodic crust movements or diastrophisms appear to be making the oceanic areas deeper and larger in comparison with the continents.

CHAPTER VIII

THE DAWNING OF EARTH HISTORY: ARCHEOZOIC ERA, AGE OF MARINE LARVAL LIFE

In the previous chapter we followed the origin of the Earth out of the Sun during Cosmic time. It was then an intensely hot globe of gas, which slowly cooled into a dark orb eventually covered by a crust. Over this crust or lithosphere lay a very thick atmosphere in which water vapor played the largest part. Then came Azoic time, when the crust differentiated into oceanic depressions and upstanding continental areas. As the lithosphere grew thicker and colder, the water vapor in the thick blanketing gaseous envelope condensed into rain, which drained into the depressions, giving rise to the oceans, and as a result the atmosphere was greatly thinned. The Sun could now shine through and illuminate the Earth's surface, bringing about conditions favorable for the origin of life in the oceanic waters. Next we are to study the Archeozoic era, the one in which geologic history actually begins. This era and the following Proterozoic one are together spoken of as Pre-Cambrian time.

Sir William Logan and the Beginning of Pre-Cambrian Geology. — The rocks beneath the Paleozoic were among the last to be described. In Europe, wide areas of these formations occur only in the Scandinavian countries, and here the difficulties of interpretation are so great that the problem was long pushed to one side. It was not until that doughty Scotch-Canadian, Sir William Logan, came back to this continent in 1842 to undertake the organization of the Geological Survey of Canada, that the Pre-Cambrian began to be studied. As a matter of fact, these very old rocks naturally thrust themselves upon Sir William's attention, since they occupy about 2,000,000 square miles out of Canada's total of 3,600,000! With the trend toward the development of natural resources characteristic of a young and eager country, he pushed his initial venture eastward in search of coal, with which he was most familiar from his work in England. But after a few years' work in Quebec and the Maritime Provinces, he turned westward and began his attack on the extensive Pre-Cambrian areas north of the Great Lakes, influenced, no doubt, by rumors of mineral wealth brought back by early explorers. About ten years after his arrival in Canada, he was ready with a broad classification of the Pre-Cambrian that was not improved on for a long time, and still remains the foundation on which present knowledge has been built. According to the fashion of the day, he at first called these rocks Primary, but in the course of his work he classified them into two or possibly three divisions. Supposedly oldest was the *Laurentian system*, consisting of crystalline rocks that he regarded (wrongly) as probable metamorphosed sediments, and named after the Laurentide Mountains along the north shore of the St. Lawrence River. Included with these was the *Grenville series* of Ontario, of which we shall hear more later. Lying unconformably over these much disturbed and altered rocks he found, north of Lake Huron, another great series, comparatively unaltered and flat-lying, which he called *Huronian*, and which he correctly considered to be even more distinctly sedimentary than the Laurentian. Finally, in the Lake Superior region, unconformable on all of these older rocks, he found, still in the position of its original deposition, a very thick series with valuable copper ores; he was in doubt about the age of this series, and finally left it with the Lower Silurian (our Cambrian). It was given the name *Keweenawan* (from Keweenaw Point, Michigan) in 1876 by T. B. Brooks, who regarded it as youngest Huronian in age.

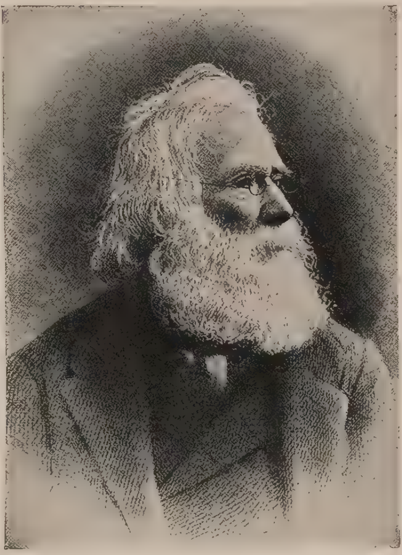


Fig. 41. — Sir William Logan (1798–1875), Father of Pre-Cambrian geology.

The Canadian Shield. — As was noted above, more than one-half of Canada is covered by Pre-Cambrian rocks, which lie, roughly, in a great wedge on either side of Hudson Bay and continue to the northeast over Greenland (Fig. 42). This is the very oldest portion of the North American continent, in other words, the first part of it to be folded into mountains and thus to rise permanently above the oceanic level. Europe has a similar area in the Baltic region, and South America in that of the Amazon. Due to the shape of the Canadian and Baltic masses, these nuclear areas of the continents have received the name of *shields*.

The rocks of the shields are now as a rule decidedly deformed and changed, due to great mountain making movements and to the upwelling of vast granite masses. Being the oldest surficial rocks, moreover, they have been longest subject to later vertical elevation and erosion, and only rarely have they been subsequently refolded into mountains. It is thought that the total amount of erosion over the Canadian Shield, for example, exceeds 6 miles in depth. Thus in the course of geologic time the shields have been transformed through

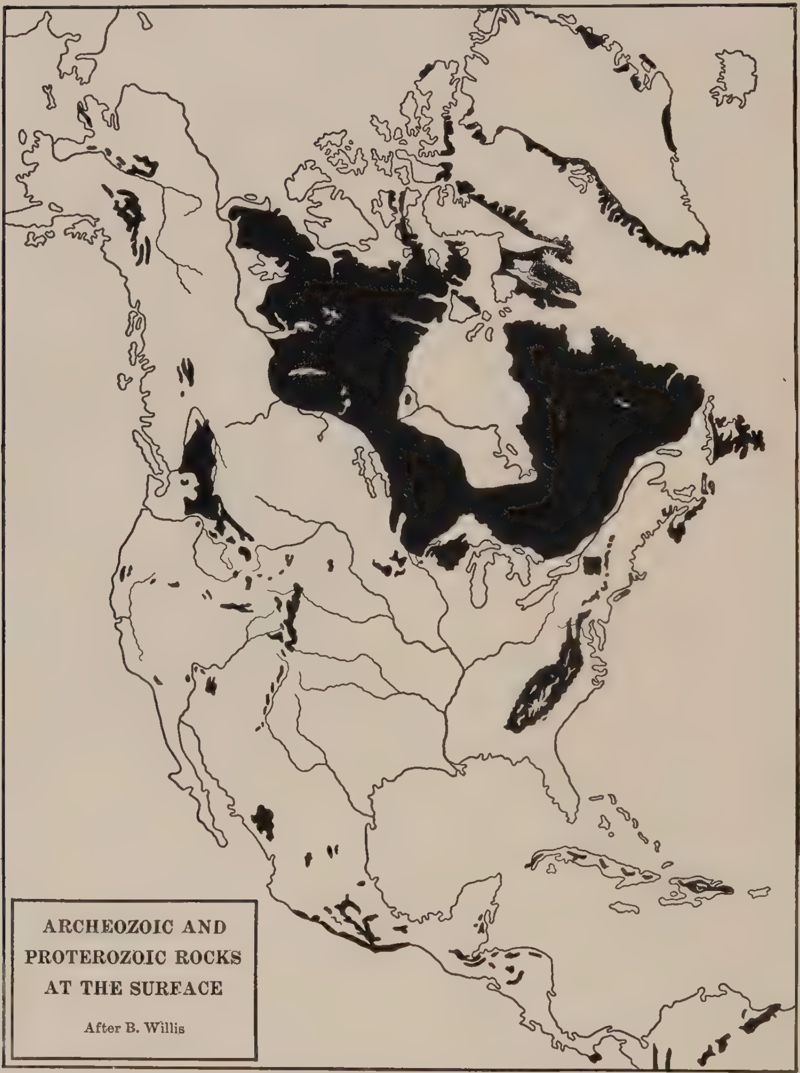


Fig. 42. — The surface distribution, in black, of the undifferentiated Archeozoic and Proterozoic formations. The great black area of Canada, together with Greenland, represents the Canadian Shield. U. S. Geol. Surv.

elevation, erosion, and sedimentation into great interior plains. Over these plains the seas of the older Paleozoic have at various times flowed widely, but of their sedimentary formations little is left.

The present Canadian Shield may be loosely spoken of as a plateau of low relief, with an average elevation of about 1500 feet in Canada (see Fig. 45). On the upturned edges of its ancient rocks rest the scattering and nearly horizontal Paleozoics, the line of contact being marked by such great lakes as Huron, Superior, Winnipeg, Athabasca, Great Slave, and Great Bear. Originally, Paleozoic strata were also widely present on the shield, but they have long since been stripped off, except in deeply down-warped or faulted areas.

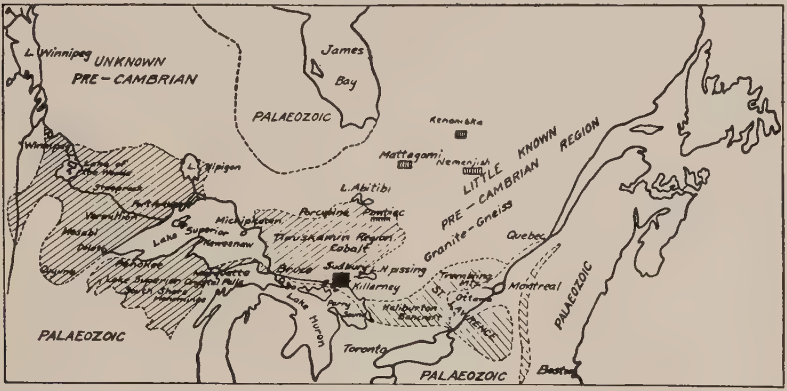


Fig. 43. — Map showing the principal regions on which North American Pre-Cambrian correlations are based. Rainy Lake lies to the east of Lake-of-the-Woods. The Grenville area is that marked Haliburton-Bancroft, to the northeast of Toronto. From Quirke.

Archeozoic Formations

Keewatin-Coutchiching Series. — For a long time after Logan's division of the Pre-Cambrian into Laurentian and Huronian, field work in these rocks " resolved itself into calling all green or gray rocks Huronian and all pink granitoid or gneissic rocks Laurentian " (Coleman). Then one day in the 'eighties a young Canadian geologist named A. C. Lawson was sent to map the Lake-of-the-Woods area in western Ontario, and his discoveries there started an avalanche of Pre-Cambrian discussion that has not yet reached equilibrium. His chief finding was that the Laurentian is not, as Logan supposed, a metamorphosed sedimentary series, but one of batholithic granites that had welled up as molten magma into a still older series. These older rocks, which are cut by the Laurentian granites, he called Keewatin, from their type locality on the lake. In other words, Logan's Laurentian rocks are of igneous origin, and therefore younger than the Keewatin into and through which they are intruded.

The *Keewatin* rocks are very largely of volcanic origin, representing a time of long but intermittent volcanism in the southern part of the Canadian Shield. During this long spell of volcanic activity, tens of thousands of feet of lavas were poured out, and these are now metamorphosed to greenstones and schists. Interbedded with the volcanics are metamorphosed sediments (now conglomerates, slates, and graywackes), for the most part of no considerable thickness or extent, though some of them run to depths of several thousand feet and lengths of 50 to 100 miles. These are thought to be fresh-water deposits.

But not even the Keewatin rocks are the oldest ones that we know. This distinction apparently belongs to a series of gneisses and mica-schists found by Lawson in the Rainy Lake district beneath the Keewatin. These, the *Coutchiching* sedimentaries, are, then, the present base of our geologic column.

Grenville Series. — In the Province of Ontario north of the lake of the same name and east of Lake Huron, occurs a succession of essentially calcareous strata, the *Grenville series*, apparently the deposits of a transgressing shallow warm-water sea. They are now known also to cover most of Labrador, Quebec, the Thousand Islands, the Adirondacks, and southern Baffin Land. In Ontario they were originally said to reach a thickness of over 94,000 feet (nearly 18 miles), of which about 50,000 feet is limestone, but rumor now has it that the thickness is less than 10,000 feet. The limestone phase is, however, practically limited to southern Ontario, the Adirondacks, and Quebec.

This Grenville sedimentary series has until recently been regarded by all geologists as of Archeozoic time, and is still so regarded by most of the men working on the Pre-Cambrian formations. The "interesting possibility" has been suggested, however, that the Grenville may be the marine equivalent of the Proterozoic Bruce series.

Grenville rocks usually extend over the ground as long bands between areas of gneissic granites, since they commonly form steeply dipping synclinal structures between the batholiths of Laurentian gneiss (see page 81). These band-like structures are due to the sediments and the granites having been folded into mountains and the folds subsequently so deeply eroded across as to expose only the granite roots of the mountains and the deeper parts of the Grenville rocks (see Fig. 47).

Serpentine is common in the Grenville marbles, and here are found the fossil-like structures known as *Eozoön*, described in the next chapter.

Because of the shallowness of the Grenville seas, and because their muds and sands came from the south, it is evident that *a great part of the northern Canadian Shield was already present in Grenville time* as a positive or continental element. This shows how far back in geologic time the rocks of this shield originated, and that the nucleus of North America probably came into existence during the formation of the Earth's original crust.

The attention of geologists has long been attracted by the abundance of graphite in the Grenville strata, chiefly in the quartzite-schists. This graphite is believed to have originated in the main from the residuum of primitive marine plants.

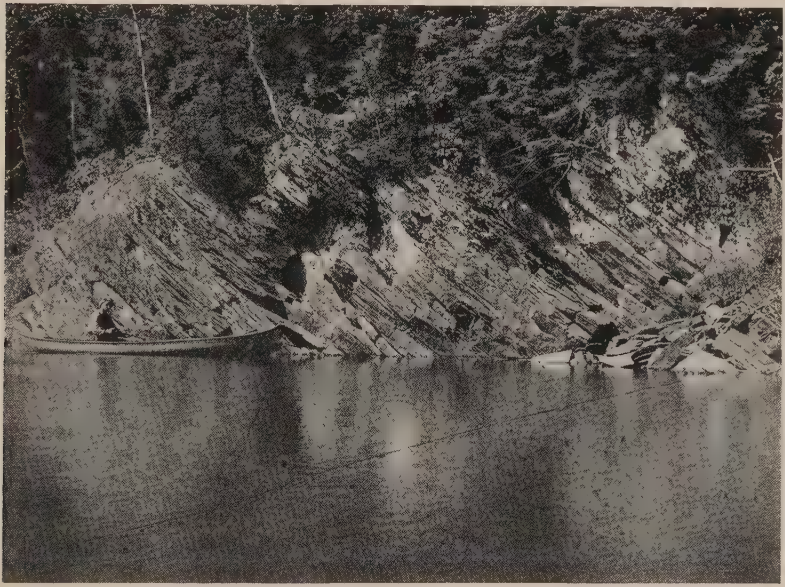


Fig. 44. — Archeozoic sedimentary rocks, the Pontiac schists, on Kinojevis Lake, Quebec, probably equivalent in age to the Temiskaming series. Tilted by subsequent crustal movements into mountains that have since been worn away. Photograph by Morley E. Wilson, Geol. Surv. Canada.

Temiskaming Series. — Much younger than the Coutchiching-Keewatin is the next well determined stage of Archeozoic history, represented again by sedimentary rocks, and known as the *Temiskaming series* from their occurrence around the lake of that name in northwestern Quebec. They are probably a delta deposit, being essentially coarse material about 20,000 feet thick; as a rule there is a basal arkosic conglomerate, followed by quartz sandstones, with from 2 to 13 per cent of shales. Carbonaceous material, however, is completely absent in this series, which is often a cleanly washed sand of fairly equal grain, coming apparently from a highland to the south and transported by rivers to a wide delta. The conglomerates are rich in boulders of an older granite. Nearly all of the Temiskaming formations are intruded, deformed, and metamorphosed by intrusive granites.

The Temiskaming series is but one of a considerable number of known sedimentary formations the exact age relations of which to one another are unknown, though all are thought to be of the same general time. One of these is the *Steeprock* limestone from Steeprock Lake, Ontario, which has the fossil sponge called *Atikokania* (see Fig. 52), and is therefore held to be of marine origin. Where the Temiskaming series and related formations are not intruded by younger igneous rocks, they are but little altered, so that the original bedding, cross-bedding, and even the ripple-marks, can still be seen on weathered outcrops. In fact, as the strata are so very ancient geologically, their modern appearance is the most surprising impression made on the observer (Fig. 44). From this we conclude that the atmosphere must have resembled that of later times in composition; water did its work then as now, and the extremes of heat and cold seem to have been normal.

TABLE OF ARCHEOZOIC FORMATIONS

(Mainly of the Canadian Shield)

Late Archeozoic time	Ep-Archeozoic interval of land erosion Mountain making and intrusion of granites (Algoman, ?Laurentian)
Middle Archeozoic time	Temiskaming series of land and marine deposits. Includes Steeprock and other formations Erosion interval and mountain making, with intrusion of granites (= Laurentian of Logan)
Early Archeozoic time	[?Grenville marine sedimentary series. Usually placed here but may be the equivalent of the Bruce series at the base of the Proterozoic] Keewatin volcanics with some land sediments Coutchiching sediments

Archeozoic Areas outside of Canada. — Archeozoic rocks are also to be found outside of Canada in the Thousand Islands region, and form a large part of the Adirondacks; and similar ancient rocks occur in the southern Appalachians and elsewhere. In the Grand Canyon of the Colorado, intruded and metamorphosed Archeozoic rocks (Vishnu series) are exposed in the Granite Gorge for 40 miles (Fig. 49). In southern Arizona they are known as the Pinal schists. Rocks of Archeozoic types are present also in Greenland, in the Baltic Shield, in Finland,

and in the Scottish highlands, regions that were probably at one time connected with Canada.

Laurentian-Algoman Revolution. — The chief Archeozoic rocks exposed over the surface of the Canadian Shield are the "pink" granites and gneisses described by Logan as the Laurentian series. So prevalent are these gneisses that they cover more than 90 per cent of the Lake Superior country, and for a long time, as we have seen, they were regarded as the original cooled surface, or crust, of the Earth, upon which the above-described formations were believed to rest. It is now clear, however, that these granites are not older than the formations which they underlie and cut through, but that they are really younger, for they represent the consolidation of numberless batholiths that welled up as molten magma into older volcanic and sedimentary strata. In other words, these Laurentian granites are intrusives and therefore clearly younger in age than the Keewatin and Coutchiching formations which they cut (see Fig. 47). It is, however, not yet established that the Grenville and Temiskaming formations are cut by these same granites, though they are intruded and traversed by very similar ones. The latter granites are typically developed in the Algoma district of western Ontario and hence are called Algoman. Some geologists maintain that all these granites are of one time of intrusion and that it is the Laurentian ones that cut all the formations mentioned; others hold that there are two almost identical granites, of different Archeozoic ages, an older and less significant one, the Laurentian, which cuts only the Coutchiching, the Keewatin, and possibly the Grenville; and a younger dominant Algoman granite which cuts the three formations just cited and the Temiskaming besides.

The reason why the granites are now so prevalent at the surface is because nearly all the roofing rocks into which they rose have now been eroded away; in other words, we are seeing rocks that were once deeply buried, possibly 6 miles or more.

The tremendous Laurentian granitic intrusions accompanied or followed a great mountain making that probably affected much of Canada, and certainly its southern part from Lake Superior eastward, including the Adirondacks, where the folding resulting from it is very apparent. These old Laurentian mountains may have had the height and grandeur of modern ones. Later on, after repeated vertical uplifts, their total depth of peneplanation (erosion) was greater than that of most other mountain systems (see Fig. 47). They are, however, not to be confused with the present residual mountains of the same name north of the St. Lawrence, which were eroded out of the plateau there probably in late Cenozoic time.

With the Algoman granites came up certain of the gold ores of the Kirkland Lake and Porcupine areas of northern Ontario, which have helped to give Canada third place in the world production of this precious metal.

Ep-Archeozoic Interval and Peneplanation. — Following the time of Laurentian-Algoman mountain making came a very long erosion interval during which these mountains were reduced to a nearly level plain. *This erosion interval is one of the longest and most significant of the geologic unconformities* or intervals of lost record; and it gave rise to the most remarkable of all known peneplains, which is a striking feature of the region north of Lake Huron even to-day (see Fig. 45).

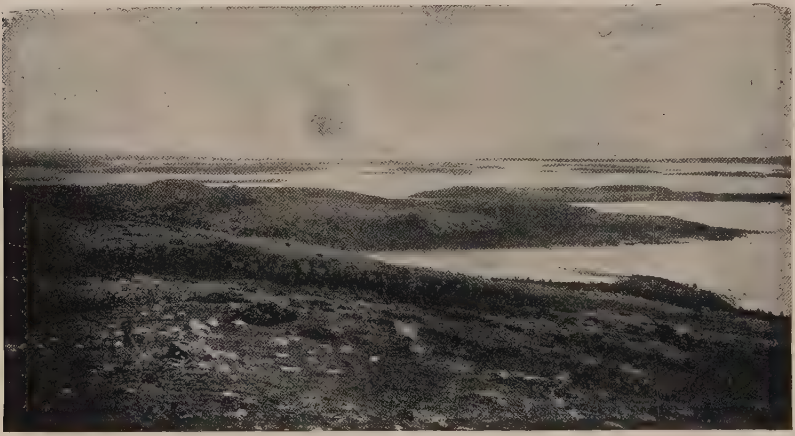


Fig. 45. — Laurentian peneplain, as seen from Lake Michikamau, Labrador. Photograph by A. P. Low. Yale University Press.

The Archeozoic Era in General

The Unseen Original Crust. — In the previous chapter, when presenting the hot gaseous theory elaborated by Jeans, it was stated that the molten Earth of Cosmic time cooled more and more, and in the Azoic era became encrusted by a cold shell of hard rock. Most geologists believe that there was such an original crust, and that it was composed in the main of granite-like rocks, but as yet no one has been able to demonstrate this original foundation upon which rest the oldest rocks in North America, the Keewatin lavas and the Coutchiching sediments. At first it was thought that the Laurentian-Algoman gneisses and granites actually were older than the previously mentioned formations and accordingly represented this original crust, but when it became evident that these igneous masses are intruded into and cut through the formations above, this conclusion naturally had to be abandoned. The same condition of things appears to occur in other continents, so that the ascertained evidence as yet nowhere reveals an original crust. This remarkable lack of evidence led Chamberlin long ago to postulate, under his planetesimal hypothesis of Earth origin, that there never was such a crust nor was there a molten Earth. According to this theory the exceedingly thick lithosphere was slowly formed by the infalling of the cold planetesimals.

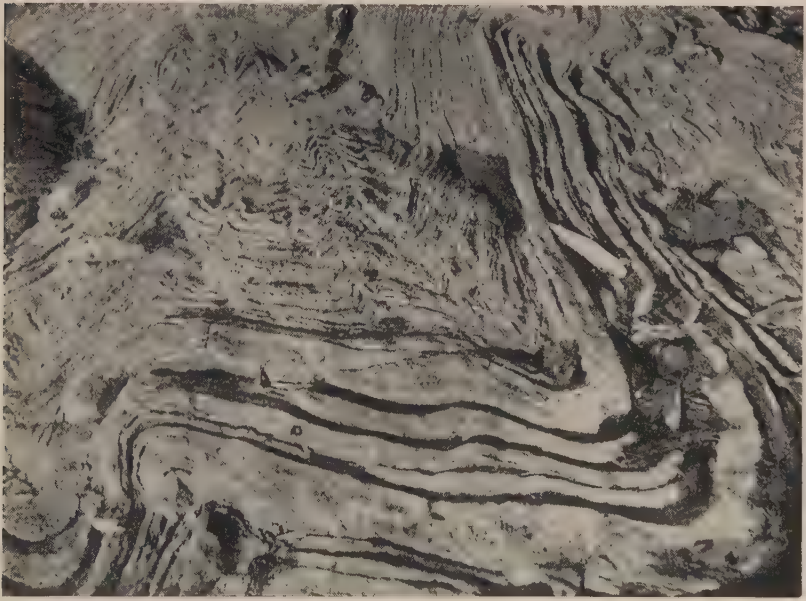


Fig. 46. — Archeozoic limestone with inclusions of gneiss, altered and contorted by pressure and heat during subsequent crustal movements. Papineauville, Quebec. Geol. Surv. Canada.

Archeozoic Difficulties. — Archeozoic rocks are exceedingly difficult to interpret. The obvious reasons for this are: (1) they are for the most part igneous; (2) the formations are seldom in their original attitude; (3) none of them are in their original condition, but all are highly altered to gneissic granites, crystalline schists, and quartzites, whose former nature can rarely be determined except under the microscope (Fig. 46); (4) they contain no fossils, since life was then mainly minute and soft-bodied and therefore not preservable. These conditions might, it is true, all obtain with much younger rocks that have been in an intruded and folded portion of the crust, but they are greatly exaggerated in those of the Archeozoic. That these very ancient rocks are now exposed over the shield is due to the fact that this vast region has been a rising one ever since it first came up above sea-level. Seas at various times flowed over the shield during the older Paleozoic as they often did over other parts of North America; mountains were built out of it several times before the Cambrian; immense masses of hot granites were thrust into the sedimentary rocks; and tremendous amounts of lavas poured out over them. But the shield continued to rise, and thus to give the forces of erosion opportunity to eat away the sediments and volcanics and level the plateaus and mountains until the deep-seated igneous rocks (granites) were exposed at the surface. We say that certain of the younger mountains are now worn down to their roots; the shield mountains, to continue the analogy, are worn down to the very bases of their roots, once deep within the lithosphere (see Fig. 47).

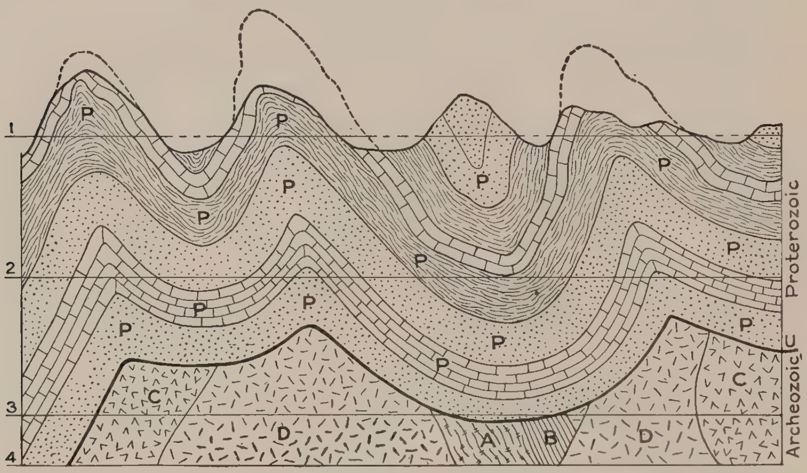


FIG. 47. — A much generalized diagram to show the extent to which the Canadian Shield has been denuded of its Pre-Cambrian rocks. *A*, Keewatin; *B*, Coutchiching; *C* and *D*, Laurentian-Algoman granites. Below are the folded Archeozoic formations that were eroded to a peneplain (*U*) and then deeply covered by Proterozoic strata (*P*). Subsequently the whole series of rocks was again folded into mountains, causing the peneplain *U* to be highly deformed.

Lines 1 to 3 represent successive levels of erosion, the distance down to line 3 being 6 miles or more. The original surface of the Proterozoic mountains, above line 1, is to be compared with young, unworn mountains like the Coast Ranges. When erosion has planed down to line 2, a stage is reached comparable to that of the Appalachians, which are worn to their roots. Line 3 represents the present surface of the Shield.

Remembering that Archeozoic time has to do with the " Dark Age " of geologic history, and that it began something like 1500 million years ago, and lasted about 500 million years, the wonder is that we have anything at all definite to relate!

Methods of Correlation. — Since there are no fossils in the Archeozoic rocks to indicate their relative ages, the criteria used in the working out of the geologic sequence are of a physical nature, as follows: (1) similarity of rock character, (2) structural nature of the rocks, (3) superposition of the formations, (4) crustal movements, and (5) cycles of erosion. The study of the various Pre-Cambrian formations makes it clear that their two most significant and distinctive features are: (1) the widespread crustal revolutions, characterized by vast upwellings of molten rocks; and (2) the profound depth to which erosion has planed, revealing, over great areas of the crust, levels whose original place was miles beneath the present surface.

Over great parts of the shield, the Archeozoic rocks, though in places present in great thicknesses, are known only in isolated areas, and, as lithology is at best an uncertain guide when formations can not be continuously traced, these rocks can not as yet be readily correlated with others elsewhere, but have received many local names. This is especially true of the sedimentaries, which stand out in the maze of igneous rocks as long and relatively narrow bands, representing the deeper parts of the synclinal folds (see Fig. 47). Fortunately, however, the north shore of Lake Huron and both shores of Lake Superior afford an area in which the formations can be traced out from place to place, and can be linked up with the Lake-of-the-Woods and Rainy Lake areas of western Ontario. By far the greater part of our established Pre-Cambrian sequence comes from work in this region.

With all these things in mind, it must be clearly understood that no discussion of Archeozoic (or Pre-Cambrian) history can be given with the certainty that marks the discussion of the later eras. All that can be done at present is to indicate the few formations that seem to be definitely ascertained and leave their final order of superposition until further work shall tie them together into a demonstrable history of the happenings that took place before Proterozoic time.

Archeozoic Life

For many years the oldest known fossil was supposed to be *Eozoön canadense,* "the dawn animal of Canada," described by Sir William Dawson in 1865 and wrongly regarded by him as a protozoan. *Eozoön* is discussed in the next chapter, and it need only be said here that as this fossil occurs in the Grenville series, which may turn out to be Proterozoic, its age is uncertain. On the other hand, the Steeprock marine sedimentary formation of the north shore of Lake Superior, which appears to be of Archeozoic time, has the unmistakable fossil known as *Atikokania*, which appears to be a sponge. If so, we have clear evidence that life had evolved at least as far upward as the sponges at this early time in Earth history. These fossils will also be described in the next chapter.

The only other direct testimony is of marine plants, blue-green algæ (Cyanophyceæ), in the Vermilion formation of Minnesota, which is of Archeozoic age.

In conclusion, all that can be said in regard to the Archeozoic is that life was present, and that it probably originated early in this era rather than in the older Azoic era. Since life was present in Archeozoic time, most of it appears to have been restricted to the sunlit upper levels of the oceans, mainly as minute floating organisms, probably single cells like modern bacteria, though higher types of Protophyta and Protozoa must have been present. In the shallow waters on the sea bottoms lived the lime-secreting algæ, and perhaps sponges also, as seen in *Atikokania.* The microscopic blue-green algæ noted in the previous edition of this book as present in Archeozoic rocks seem, according to later investigations, to be structures made through chemical osmotic pressures and therefore are not of organic origin.

CHAPTER IX

THE PROTEROZOIC ERA: AGE OF PRIMITIVE MARINE LIFE

The Proterozoic era, the second in the geologic history of the Earth, is as long as the preceding Archeozoic and much more interesting. Broadly interpreted, it embraces the same time as Logan's Huronian. As indicated by radioactive minerals, it occupied about 30 per cent of geologic time and endured, roughly, 500 million years. It is the time of primitive marine invertebrates, furnishes much undisputed evidence of the invasion of the continents by the oceanic waters and therefore the first determinable paleogeography, and was probably the grandest time of ore making in the history of the Earth. In the area of the Rocky Mountains at least 37,000 feet of marine and fresh-water sediments were laid down (Beltian), and in the Lake Superior region upward of 53,000 feet of mainly continental sediments with marine ones (Animikian), and in addition 35,000 feet of volcanics; but even these large figures do not at all suggest the long history of Proterozoic time, due to the very marked imperfection in the sedimentary record. The known history of the Proterozoic era is mainly one of erosion with local recording of continental deposits and with at least one clearly determined and long-enduring marine invasion (Animikian).

The North American Continent in Proterozoic Time (Pl. 1). — From the geographic position of the earliest Paleozoic (Lower Cambrian) seas upon the continent of North America (see Pl. 7) and those of the Middle Proterozoic as well (Animikian-Beltian), it is plain that this land mass was not only outlined in much of its present form at least as far back as the Early Proterozoic, but that it was even larger than it is now. How much larger will never be directly known, but seemingly it was then and for a long time subsequently widely connected by dry land with Greenland, and eastward across the sea with Scandinavia. Much land must also have extended west beyond the present Pacific coast, and Central America appears to have continued eastward, making a far greater Antillia than the present dismembered islands. Accordingly it is believed that more than 1,500,000 square miles of greater North America have broken down into the oceanic basins since Proterozoic time.

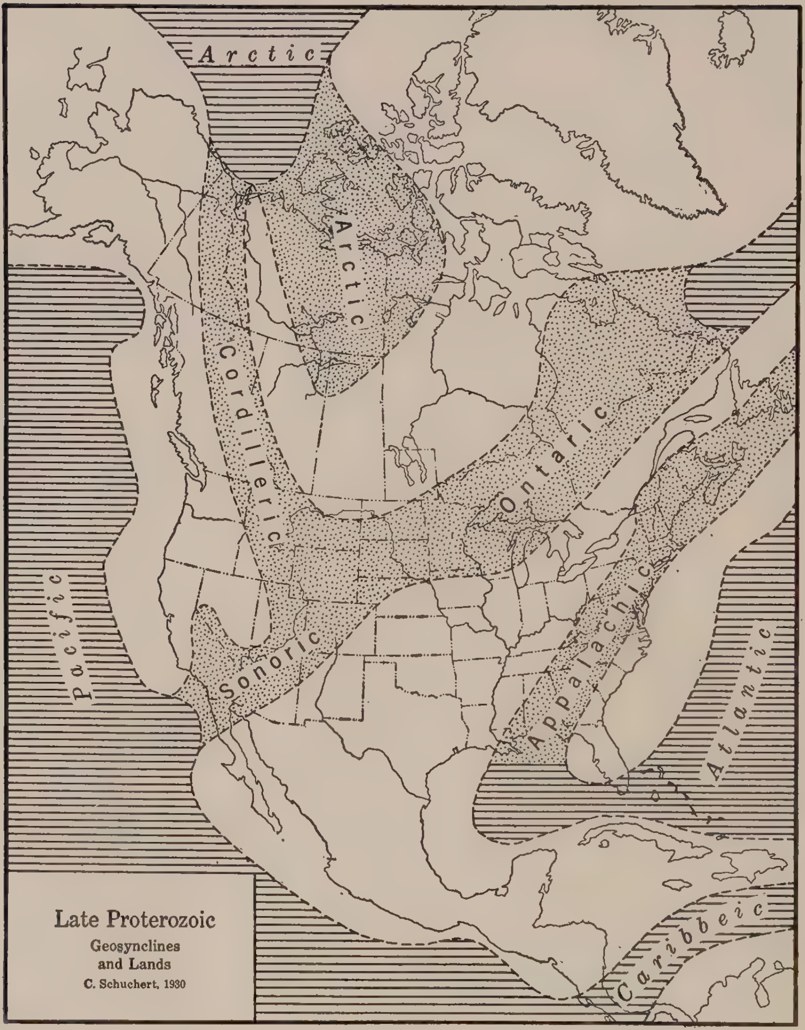


Plate 1. — North America during the later Proterozoic, showing the three geosynclines: (1) Appalachic, (2) Cordilleric, and (3) Ontaric-Sonoric. The fourth seaway (Arctic) appears not to have been a geosyncline, but rather an epeiric sea similar to those of the Paleozoic. For a discussion of geosynclines, see Chapter X.

The Proterozoic Time-table. — To give a bird's-eye view of what is to follow, we present the following little time-table:

TABLE OF PROTEROZOIC FORMATIONS

(Mainly of the Canadian Shield)

Late Proterozoic or Keweenawan time 250 million years	Epi-Proterozoic or Lipalian erosion interval, possibly enduring 180 million years. Tillites in western Europe, Greenland, Australia, China, etc.	
	Killarney or Penokee mountain making and intrusion of Killarney granite	
	Keweenawan volcanics and continental strata of Lake Superior region	
Middle Proterozoic or Late Huronian time 75 million years	Erosion interval	
	Beltian marine series of Rocky Mts.	Probably not of the same age
	Chuar-Unkar series, mainly continental, of Grand Canyon, Arizona, terminated by making of Grand Canyon mountains	
	Animikian marine series. Great Iron Age	
Early Proterozoic or Early Huronian time 200 million years	Erosion interval	
	Cobalt series, in the main continental, with oldest tillites	
	Erosion interval	
	Bruce series, in the main continental.	

EARLY PROTEROZOIC OR EARLY HURONIAN TIME

Disregarding the debatable Grenville series (see page 78), the history of the early part of Proterozoic time, as recorded in the region north of Lake Huron, seems to have been (1) a long period of continental sedimentation, when great amounts of erosion materials were being brought down from highlands to the south; (2) vertical uplift followed by erosion; (3) another long period of continental deposition, in the course of which occurred the first known glacial climate in the history of the world.

Bruce Series. — By the end of the Archeozoic, the rocks of the Canadian Shield were worn down to a leveled surface much like that of to-day. Over these planed-off crystallines, in the Lake Huron area, there was laid down in the Early Proterozoic a series mainly of continental deposits, known as the *Bruce series* from the area around the Bruce copper mines not far from Sault Ste. Marie, in Logan's original Huronian district. These beds range in thickness from 2700 feet in the north to 13,000 feet in the south, hence the material of which they are composed is thought to have come from highlands in the latter direction. They are conglomerates, quartzites, and slates, with some impure dolomites. The strata appear to be largely of fresh-water origin, because of their irregularity of deposition; however, the presence of dolomite, which is a marine deposit, shows that seas must have had access to the region, at least locally, and accordingly the series may be the deposits of a delta, with the sea to the north.

Cobalt Series. — The deposition of the Bruce series was followed by a time of uplift, succeeded by the inevitable erosion. When the land was worn down sufficiently, the region again became one of deposition, receiving another thick set of beds called the *Cobalt series*, after the famous Cobalt nickel-cobalt-silver district some 300 miles north of Toronto. The series includes more than 12,000 feet of slates, quartzites, iron-ore beds, dolomites, and conglomerates, probably in large part of continental deposition. Its special interest lies in the presence of tillites in the Gowganda conglomerate at its base. The glacial climate indicated by these tillites is discussed later in the chapter.

Possibly of this time is the Grenville series, the age of which is not yet agreed upon (see page 78).

Middle Proterozoic or Late Huronian Time

Animikian Series. — The middle portion of Proterozoic time is also recorded in the Great Lakes region, and in addition in the Rocky Mountains on both sides of the International Boundary. Leaving out of consideration the Grenville series, the Great Lakes region now for the first time came for a long time under the full influence of the sea, which laid down marine deposits that were evidently once of wide distribution. These form the *Animikian series* of the Lake Superior shores (called Whitewater north of Lake Huron). The formations making up this well established series (there are at least eighteen) are not now of universal distribution over the shield; on the contrary, the areas are widely isolated and appear in the main to be remnants preserved from erosion in downfolded or downwarped basins in the older rocks. They are in general schists, slates, iron-ore beds, quartzites, and conglomerates, with volcanic tuffs and diabase intrusions in places. In the Penokee area of Minnesota those that remain after their long exposure to erosion are still 14,000 feet thick, but elsewhere they are usually reduced to a maximum of about 6000 feet.

In the higher portion of the Animikian series there are great thicknesses of black slates containing so much carbon that if it were concentrated the total would, it is estimated, make a bed of anthracite 200 feet thick. This vast amount of carbon implies the presence of much marine life, and such an abundance of organisms means a plentiful supply of free oxygen in water and atmosphere, since all life other than certain of the bacteria (anaerobic) must have this gas in order to live. The red color of certain of the Keweenawan and Animikian oxidized sediments may indicate an increase in free oxygen to the point where it became effective as an enormous stimulant to the animal kingdom.

The widespread and shallow Animikian seas were peculiar in another respect, in that their waters contained in solution and deposited more iron than is known to have ever occurred in similar seas. Originally, the iron was far more disseminated in the strata than it is now, but since these rocks lay near the surface for hundreds of millions of years, the rains soaked through the strata thoroughly, dissolving away most of the lime and silica and so concentrating the iron into the present rich beds. Almost all of the areas have an "iron formation," which in places runs to 1000 feet in thickness, and from which have been formed the ore bodies. The greatest of these ore bodies lie in the Mesabi district of Minnesota; from that state, Michigan, and Wisconsin came in 1927 over 50 million tons of iron, 84 per cent of the total tonnage mined in the United States that year. The rich ores from this great iron series have been no small factor in the present great industrial expansion of the United States. Iron-bearing series of similar age occur on Hudson Bay, and in Brazil.

Beltian Series. — In the Rocky Mountains, the Middle Proterozoic is represented by a thick sequence of sandstones, shales, limestones, and mud-cracked red silts known as the *Beltian series* (from Belt, Montana), which is found also in Idaho and British Columbia north to at least 54°. These strata may be equivalent in age to the Animikian and they may be younger. They are partly marine, recording the first known invasion of the seas in the West. Their special interest lies in the life of the sea they contain — algal growths and worm tubes and trails, described later in the chapter.

Proterozoic of the Grand Canyon Region. — Further to the south, a marine delta was also spreading over the Grand Canyon region, laying down the older Unkar and the younger Chuar formations with a thickness of nearly 12,000 feet, mainly sandstones, now exposed in the lower walls of the Canyon. It was, however, a temporary sea invasion, leaving only 435 feet of limestones, which quickly pass upward into the continental type of beds of the delta series. These formations rest on the peneplained surface of the highly deformed and intruded Vishnu strata of the Archeozoic, and appear to be of Middle Proterozoic time (see Fig. 49).

Grand Canyon Mountains. — After the deposition of the Unkar and Chuar sediments, the rocks of the Colorado plateau were profoundly block-faulted, tilted eastward, and elevated into a monoclinal attitude, and the resulting mountains were presumably high and in aspect not unlike the present Great Basin ranges. What time relation the making of these Grand Canyon mountains bears to the making of the Killarney ones described beyond is unknown. All the western mountains appear to have been eroded to sea-level before the Paleozoic era began, for the horizontal Middle Cambrian strata here rest upon the peneplained older formations (see Fig. 49). The mountain making may not, however, have been of wide occurrence, since to the north in the Rocky Mountains of Montana, Idaho, and British Columbia the Beltian series shows no angular unconformity where it lies in contact with the Paleozoic above (see further remarks under Lipalian interval).

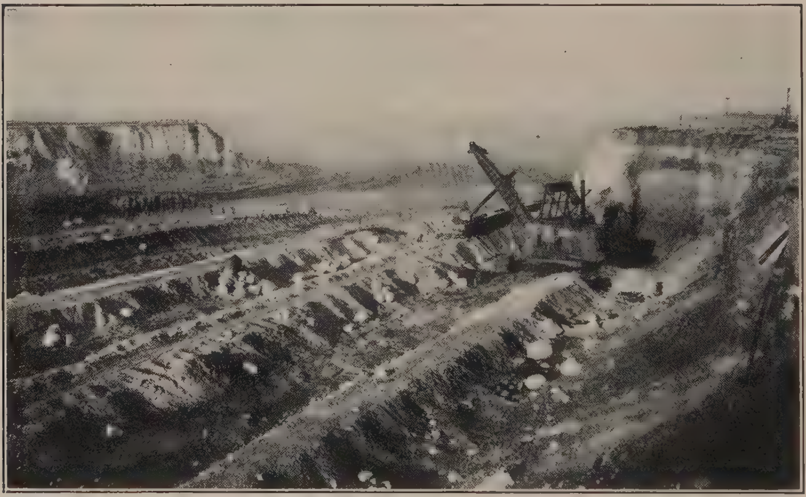


FIG. 48. — Open cut iron mine in the Mesabi Range, Minnesota. Photograph by Gallagher.

LATE PROTEROZOIC OR KEWEENAWAN TIME

Following the Middle Proterozoic events, North America remained land continuously until the beginning of Paleozoic time. For the 250 million years of the Late Proterozoic the only sedimentary record appears to be that of the deposition of the volcanic and continental strata of the Keweenawan series. In the interval between the laying down of this series and the beginning of the Paleozoic era lies Lipalian time, to be discussed on a later page.

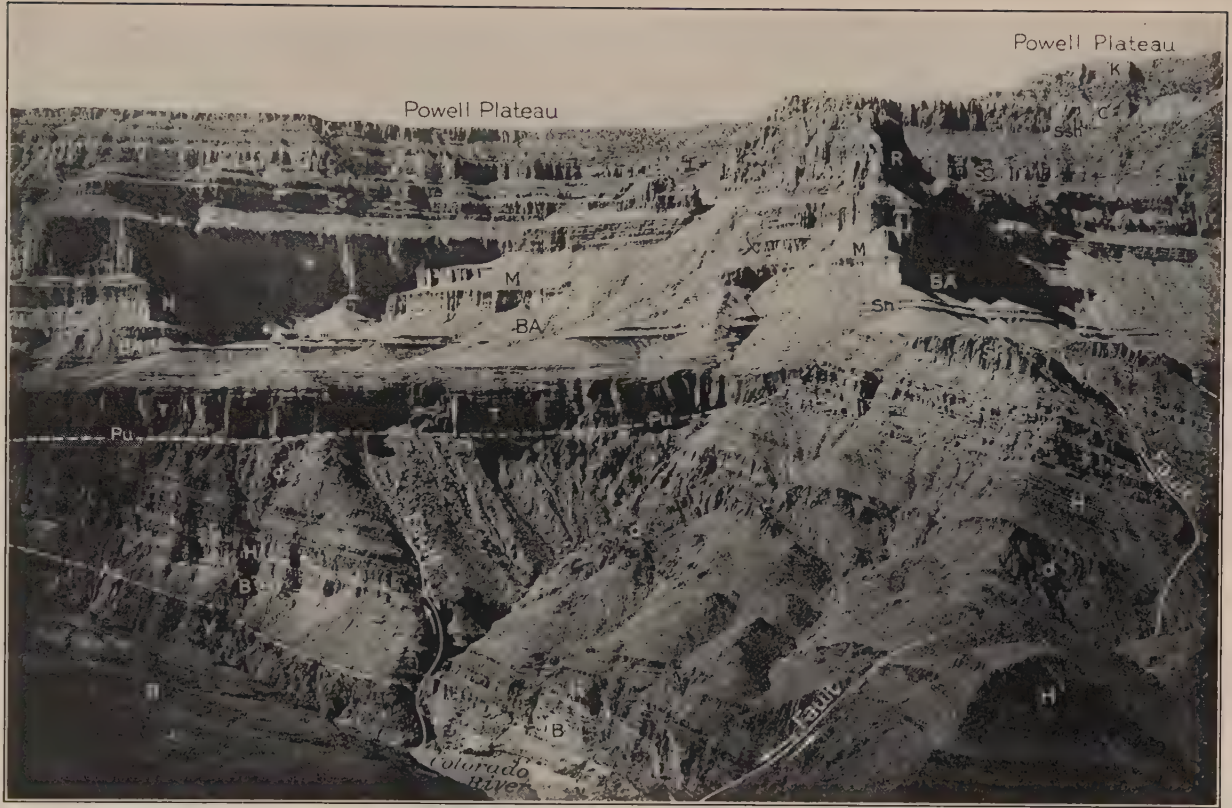


FIG. 49. — North wall of the Grand Canyon (Shinumo quadrangle), showing a vertical mile of strata. At river level is the Archeozoic (V); higher, the much faulted Proterozoic (B, H, d = diabase intrusive, and Sh); at the top the Paleozoic (T, BA, Sn, M = Cambro-Ordovician; R = Mississippian; Ss, Ssh, C, K = Permian). See also Fig. 77.

Note the two great unconformities, Au below and Pu above; the upper one shows, at the right, the Proterozoic extending up about 200 feet into the Paleozoic, which means that in the older Cambrian sea there was an island here. Photograph by N. W. Carkhuff, U. S. Geol. Surv.

Keweenawan Series. — Above the Animikian in the Lake Superior region comes the *Keweenawan series* of rocks, first described by Logan, which are all of continental origin and of quick accumulation. There is a distinct break in the record between the two series, and, moreover, the sediments of the former are of marine origin.

The Keweenawan is characterized by enormously thick deposits, both of lavas and sediments, the igneous activity rising to a crescendo in its middle and upper portions. The sediments are largely derived from the Laurentian-Algoman granites, but red jasper pebbles of the iron formations also occur. Ripple-marks are common, the sandstones are often feldspathic and might be called arkose, and the shales have mud-cracks, all of which are indicative of continental origin. Further, the prevailing color is red, like the Triassic of the Connecticut Valley, suggesting at least seasonally dry conditions and complete oxidation.

This closing time of rock recording in the Proterozoic is marked in the region of Lake Superior by a tremendous outpouring of volcanic materials upon the dry lands, probably not by volcanoes but rather through fissures. It was one of the greatest volcanic floods of geologic time, the volume of known igneous material extruded being estimated at 24,000 cubic miles. In northern Michigan and Wisconsin the total depth of the Keweenawan may be 50,000 feet, of which only about 15,000 feet is interbedded detritals like conglomerates, sandstones, shales, and wind-blown volcanic ash and lapilli, while the remainder is lava.

As previously stated, Logan was very uncertain as to the age of the Keweenawan series, but finally placed it in the Paleozoic; and several leading geologists retain the opinion that these lavas and sediments are of Cambrian time. The field relations are still obscure, but since no fossils have yet been found in the main mass of the series, it seems best to hold to the more popular conclusion that most of the Keweenawan is of Late Proterozoic time. We shall probably learn in this instance, as in other controverted ones, that the Keweenawan contains formations of both eras, the bulk being Proterozoic while the youngest red beds immediately beneath the Upper Cambrian are those of a seasonally dry delta shortly preceding the marine invasion just mentioned. Some of the red beds are known to have scattering Cambrian fossils.

Proterozoic Mineral Wealth. — The Keweenawan series has been a tremendous asset to Canada, endowing her with 90 per cent of the world's output of nickel, with silver to the value of $240,000,000 taken from one district alone (Cobalt) since 1903, and with other valuable metals. In the Sudbury district to the north of Georgian Bay the copper and nickel ores occur around the edges of a great intruded sheet of norite, and with them are gold, silver, and platinum in smaller amounts. The silver ores of the Cobalt district came up in Keweenawan time along with a great diabase sill. They were discovered in 1903 during the construction of a railway projected to open up the agricultural areas to the north, and in the next ten years the value of the ore produced equaled five times the cost of constructing and equipping the railway, plus dividends equal to two and a half times its total cost! The silver here is not in the usual lead ores, but in the native state, and at one time ran 1300 ounces to the ton, the average yield being 150 ounces. Associated with it are cobalt, arsenic, and nickel. At Thunder Bay the silver ores were supplied by Keweenawan diabase dikes and sills. Ontario's metal yield for 1926 was valued at $59,218,297.

In the matter of copper, the Keweenawan was perhaps rather more generous to the United States, though Canada has a 9-mile thick copper-bearing series, of Late Proterozoic age, along the Coppermine River in the extreme north of the shield, from which the Eskimos long ago took native copper for their tools and weapons; and another extensive copper area east of Great Bear Lake. The Lake Superior copper region of the United States, also worked in prehistoric time, was rediscovered in 1830 and has been a steady producer since 1847. Great fortunes have come from this part of the country, notably from the famous Calumet and Hecla mines. Particularly rich are the mines of native copper on Keweenaw Peninsula, Michigan, which in 1927 yielded 97,560 tons of this metal so widely used in our present age of electricity.

After the close of the Keweenawan, no important ore deposits, so far as known, were formed within or near the Canadian Shield. The flows of magma during this vast Late Proterozoic upwelling "seem to have exhausted the treasure-house" (Coleman).

Killarney Revolution

Apparently mountains were made in Late Proterozoic time at different epochs and at different places in the various continents. In North America there seem to have been at least two such mountain systems, one in Arizona, previously described, and the other throughout the Lake Superior country. The other continents also show Late Proterozoic mountain systems, but as yet none of these are correlatable one with another.

In the Lake Superior region, after Keweenawan time the whole area from far northeast of Sudbury into southern Wisconsin was folded and injected by granitic batholiths, making the *Killarney mountains.* These have long been known as the "Lost Mountains of Wisconsin" (or Penokee mountains). One of the ranges extended from southwest of Duluth northeast to the south end of Lake Temiskaming. To the north of the mountains the Huronian strata are in open folds; south of them they come to be more and more closely folded and faulted, and finally, not far from the Paleozoic border, they are invaded by granitic batholiths. (See Pl. 8.)

Epi-Proterozoic or Lipalian Interval

Following the known events of the Proterozoic era, and before the introduction of Paleozoic strata with their abundance of fossils, there is an interval of very great significance. During this Epi-Proterozoic interval, which has been called Lipalian time by Walcott (from a word meaning gone or missing), the continents appear to have stood well above the general oceanic level, and the chief geologic work done was that of erosion. Therefore, the land areas of Lipalian time were reduced to a low-lying plain, a peneplain, and it was over these flat lands that the Paleozoic seas spread with their fullness of life. How much time was consumed during the Lipalian, no one knows, but it was long enough for much of the animal world to change its soft skin to one protected by a hard covering of calcium carbonate such as is seen in many of the invertebrates of the Cambrian.

This fact as thus stated may not be impressive to the student as demonstrating a long time of which no direct record is known; and so we shall go a little farther with it from a different angle and a theoretic one. In the Middle Proterozoic era certain of the Protozoa (Radiolaria, see page 48) and the sponges were the only animal types that had learned to use silica to build external skeletons — of plants none are known to have used it thus early — and not one of the animals apparently used calcium carbonate for this purpose. Crustaceans with chitinous coverings, and brachiopods and gastropods with calcium carbonate shells must, however, have been present in the Late Proterozoic. That this conclusion is sound is shown in the oldest Cambrian, where nearly all the phyla of animals have well developed external skeletons of either chitin or calcium carbonate, indicating that there was a long antecedent usage of these coverings. As evolution works very slowly through natural selection, these facts can mean only one thing, namely, that the Lipalian interval of Late Proterozoic time was a very long one. And if we add that nowhere in the world are any Late Proterozoic marine strata known, this means in addition that all the continents then stood well above sea-level. It was therefore in the time represented by these as yet unknown Late Proterozoic strata that the making of external skeletons was learned by the invertebrate animals.

PRE-CAMBRIAN CLIMATES

One of the most surprising of recent (1907) discoveries in Geology was the finding of glacial tillites (morainal deposits of glacial till or boulder clay, hardened into stone, see Fig. 50) at the base of the Cobalt series, and the consequent establishing of the occurrence of a glacial climate thus early in the history of the Earth. Over the wide Ep-Archeozoic peneplain previously described, there is found in the country to the north of Lake Huron a basal conglomerate (Gowganda) that locally includes facetted and striated boulders of various kinds of rocks. Over the tillites occur, also locally, thick zones of banded (varved) slates and water-formed conglomerates and quartzites. These are the phenomena seen so well in the glacial deposits of the Pleistocene, demonstrating all the more clearly this early ice age.

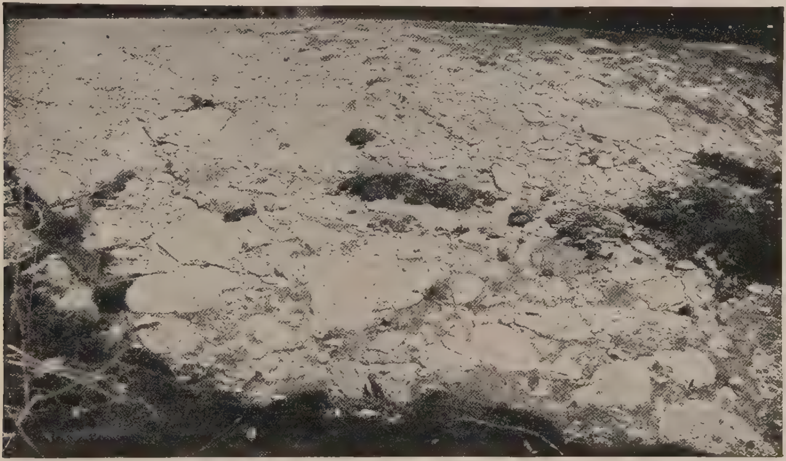


FIG. 50. — Eroded exposure of the Huronian tillite near Cobalt, Ontario. Photograph by A. P. Coleman. Yale University Press.

Undoubted tillites of probable Proterozoic age are now known in many other lands: certainly in Norway, East Greenland, China, India, Australia, and Africa. They are of different ages, some occurring at the close of the Proterozoic and others earlier. Those of Norway, East Greenland, China, and Australia appear to be so near Cambrian time that some geologists refer them to the base of the Paleozoic but we prefer to regard them as of latest Proterozoic time, since the Lower Cambrian limestone reefs indicate warm-water oceans. (See Fig. 51.)

The thick limestone series of the Proterozoic suggest that at the time of their formation the climate was at least mild. Then, too, the many zones of algal concretions, some of which are actual reef-limestones, point also to warm waters. The vast amount of iron deposited is additional confirmation of mild climates. We may, therefore, conclude that at this very early time in the history of the Earth the geologic climates were in general mild, and that the temperature belts were more uniform than they are now, but that at two or three different times cold climates developed that were, as usual, of short duration geologically.

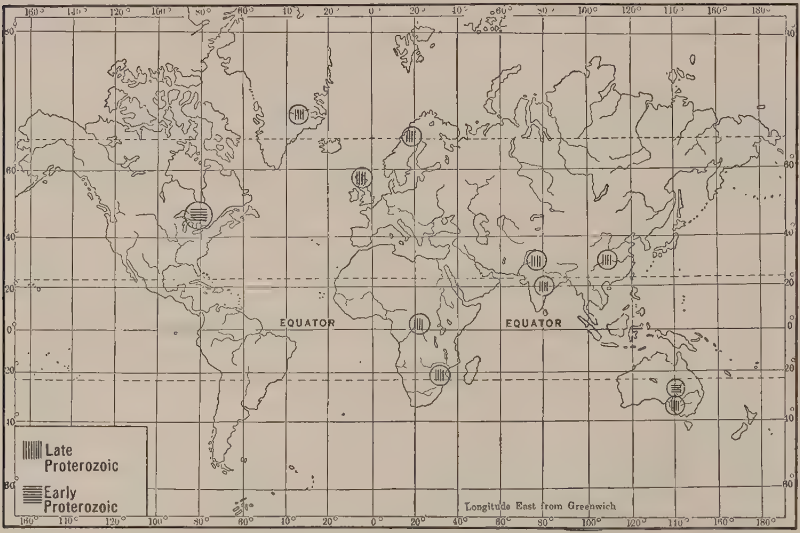


Fig. 51. — Areas of early and late Proterozoic glaciation.

Life of the Proterozoic

It is not so long since it was thought that the Pre-Cambrian strata were devoid of recognizable fossils, but during the past thirty years such have been described from various countries. All are marine or at least aquatic. In the Late Archeozoic Steeprock limestone, probable siliceous sponges occur (*Atikokania*, Fig. 52). The Proterozoic of Brittany has Radiolaria and four orders of sponges, and near the top of the Grand Canyon series (Chuar) of Arizona have been found siliceous sponge spicules.

The most abundant fossils of the Pre-Cambrian limestones, however, are the secretions of calcareous algæ (blue-green Cyanophyceæ, Fig. 53), one of which has been known for a long time as *Eozoön*. These coral-like plant masses, sometimes spoken of as coralline plants, make entire beds that repeat themselves again and again through thousands of feet of limestones. Algæ are also common in the iron strata of Hudson Bay, Minnesota, and Michigan.

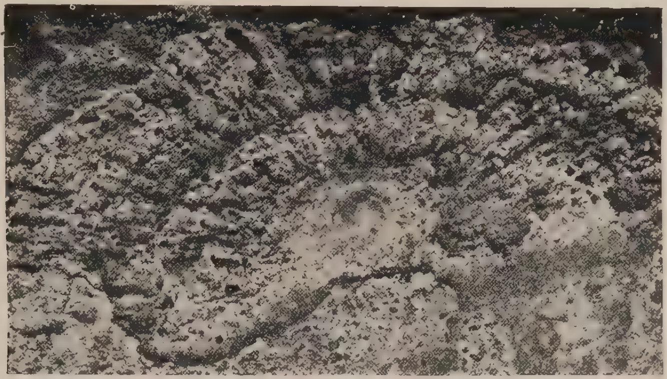


Fig. 52. — Weathered section through a probable sponge (*Atikokania lawsoni*), from the Archeozoic (lower Huronian) at Steeprock, Ontario, × 2. Geol. Surv. Canada.

The masses described by Sir William Dawson as *Eozoön canadense* consist of irregularly alternating thin calcite bands and dark green layers, usually of serpentine, and result from metamorphism of the lime deposits. They are now regarded as probably of organic origin and are thought to be calcareous depositions, made, however, by marine plants (algæ) and not by animals as the name indicates.

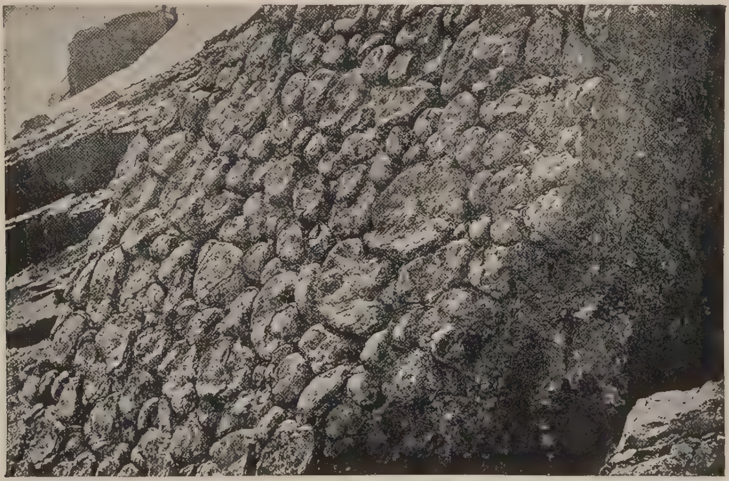


Fig. 53. — Proterozoic reef of calcareous algæ (*Collenia* ? *frequens*), Flathead County, Montana. U. S. Geol. Surv.

Indirect evidence in favor of the view that life abounded in the Pre-Cambrian is seen not only in the widespread and vast amounts of graphite in these sediments (especially Animikie and Grenville), which is largely if not wholly the metamorphosed carbon once in organic bodies, but also in the presence of the iron-ores, since iron is precipitated by the action of certain types of bacteria on disintegrating organic matter.

Finally, from the middle portion of the Proterozoic (Beltian series) of Montana have been described tubes and trails that were made by wormlike animals (Fig. 54). They are among the youngest fossils known in the Proterozoic, and even though they are only tubes and trails they seem to indicate the presence here of annelid worms, or at least of wormlike animals.

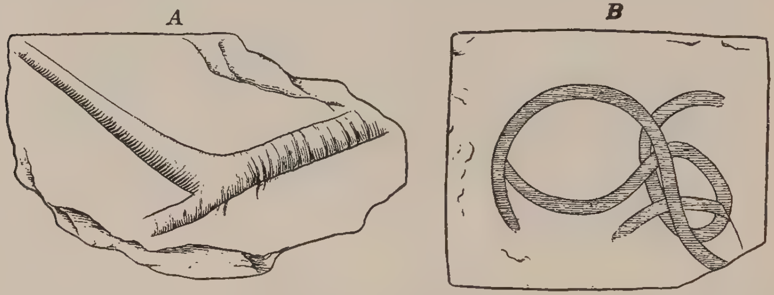


FIG. 54. — Evidence of Proterozoic worms. *A*, cast of large burrow (*Planolites corrugatus*). *B*, imprint of the actual annelid tube (*Helminthoidichnites meeki*). After Walcott.

In summation, the evidence shows that life was present in the Archeozoic and in abundance early in the Proterozoic, and that it consisted mainly of marine algæ and sponges. In the Middle Proterozoic occur Protozoa (Radiolaria), wormlike animals, and various types of siliceous sponge spicules, and from the nature of the Cambrian faunas we must infer that trilobites, brachiopods, and gastropods were also present in Late Proterozoic or Lipalian time. This means that primitive forms of most of the invertebrate classes of organisms were in existence in Late Proterozoic time.

CHAPTER X

PALEOGEOGRAPHY: THE PROCESSION OF ANCIENT GEOGRAPHIES

The geography of to-day can only be understood in the light of the geologic past, and on the other hand, paleogeography can only be deciphered out of the rocks when guided by a knowledge of the causes that bring about changes in the geography of the present. Geography has been defined as the science which describes the Earth's surface, including the distribution of the living things upon it at the present time, and man's cultural works. Paleogeography, on the contrary, treats of the geographies of the past, as known to Paleontology and Geology. It seeks not only to describe and picture the shapes and interrelations of the various lands and seas, but as well to discern, on the lands, the leading physiographic forms, besides the volcanic, desert, and glacial areas.

The geographer's methods of observation are direct, for he measures and describes what he sees, but the geographic and organic relations of any given geologic time are discerned by the paleogeographer mainly by indirect methods; he sees no actual seas and oceans, no hills, valleys, mountains, or rivers, no actual living things of any past time, yet the paleogeographic record of all these is hidden in the rocks and fossils, and can be read by him with the same facility with which the antiquarian or archeologist deciphers, in his unearthed human relics, forgotten civilizations and languages, or wholly unknown cultures.

The paleogeographer makes use of all the knowledge of the Earth's surficial formations and their internal structures, plus the knowledge of the entombed fossils and the climates indicated by these and by the sediments. The ancient geographies were automatically recorded in the rocks of the Earth's surface by the geologic processes, and this silent but significant information is obtained chiefly from the distribution of the sedimentary formations and their fossils. It is therefore the ever changing fossils, the variable rock nature of the formations, and the geologic structures of the crust that furnish the direct evidence for the deciphering of the ancient geographies. In all of this the paleogeographer is guided by the following principles:

1. The laws of nature have always operated more or less as we see them doing now, although not necessarily with their present intensity.

This principle, the *law of uniformitarianism*, is discussed further on page 7.

2. The continental masses and the oceanic basins have always been in the same relative positions in which we see them to-day. This conclusion is fundamental in paleogeography, for if there had been a repeated or irregular interchange of these areas, the discerning of the ancient geographies would be most difficult if not impossible. This matter is dealt with more fully later in the chapter, and the relations of these grander structures of the Earth's lithosphere have been described in Chapters II, VIII, and XV of Part I, which the careful student is advised to re-read as a foundation for his further studies.

3. The oceans have repeatedly transgressed the continents and as often retreated. Usually, one such completed movement takes place in the duration of a single period, but some of the periods, as now delimited, have two or three floodings (see, further, page 115). Again, minor mountain makings (= disturbances) often appear during the latter half or last third of the periods, with greater ones (revolutions) closing the eras.

The volume of water on the surface of the Earth has increased with geologic time, but the amount so added during any epoch does not appear to have appreciably increased the flooding. This so-called juvenile water comes to the surface from the Earth's interior through magmatic differentiation (see page 230 of Part I), and was given forth in greatest volume during the Azoic and Archeozoic eras.

Permanency of Continents and Oceanic Basins. — It is true, as Lyell says, that " every part of the land has once been beneath the sea," but beneath *shallow* seas and not oceanic depths. On the other hand, that " every part of the oceans has once been land " is not upheld by the slightest evidence, since it has nowhere been demonstrated that the continents have widespread abyssal or oceanic deposits; the lands that do have such deposits, as the island of Barbados off South America, are of very small extent and all of them together do not occupy more than one per cent of the land surfaces. Besides, all such places are on the margins of the continents.

In recent years there has been proposed a theory called " continental displacement," which holds that the Americas once lay closely adjacent to, or were even connected with, Euro-Africa, and later broke away and slid westward to their present positions. There probably is no truth in this wholesale displacement, but geologists have long been seeing that parts of the continents do move, and it may be that they actually move bodily, but to a limited extent. The Appalachian Mountains, for instance, along the Atlantic border of North America, show in their folded and overthrust structure a movement of the outer shell to the westward of something like 200 miles. Again, the Alpine mountains of southern Europe reveal a similar movement from the south, leading some geologists to say that Africa as a whole has moved north anywhere from 200 to 400 miles and perhaps more. It may actually be that continental movements of this order have taken place in geologic time. On the other hand, the distribution of the best known faunas of the Paleozoic and Mesozoic shows clearly that the continents since at least the Cambrian must have been about the present distances apart, for if they had been much nearer together the number of species common at a given time to two continents would be far greater than it is known to be, *i.e.*, rarely exceeding 5 per cent.

Land-bridges and Oceanic Portals. — The continents have at times in their geologic history been connected by land-bridges or separated by oceanic portals, thus greatly affecting the distributions of floras and faunas. Present Panama is a good example of a land-bridge, but it has not always been one. In Paleozoic and through two-thirds of Mesozoic time, most of Costa Rica and all of Panama were parts of the deep Caribbean mediterranean; Panama came into existence as a land late in Miocene time, but during the earlier Cenozoic (late Eocene, Oligocene, and early Miocene) the Caribbean flowed across it into the Pacific (see Pl. 31). North America and Siberia are to-day separated by the shallow portal of Behring Sea, but during most of geologic time there was an Alaskan-Siberian land-bridge here — a low land across which migrated hordes of plants and animals. Still another very ancient land-bridge once extended from eastern Greenland across Iceland to the Faroe-Shetland islands and thence to Scotland and Norway; to-day there are great oceanic depths between these lands. When the Alaskan-Siberian and Iceland land-bridges were in existence, all of the lands in the northern hemisphere were united to make a great northern transverse continent known as *Holarctica* (see Fig. 55). The present Mediterranean Sea, on the other hand, was formerly a far grander seaway, called *Tethys*, separating Euro-Asia from Africa (Fig. 55), but there have been land-bridges across it at different times and in various places.

Recurrent Spread of the Oceans over the Lands. — The many changes which the geography of the Earth has undergone are due mainly to the fact that the surface of the Earth and the oceanic level are at times in decided motion: "ages and cycles of Nature in ceaseless sequence moving." These crustal oscillations are not caused by heterogeneous and unrelated movements, but are connected, in that areas of elevation and depression remain as such during more or less long stretches of

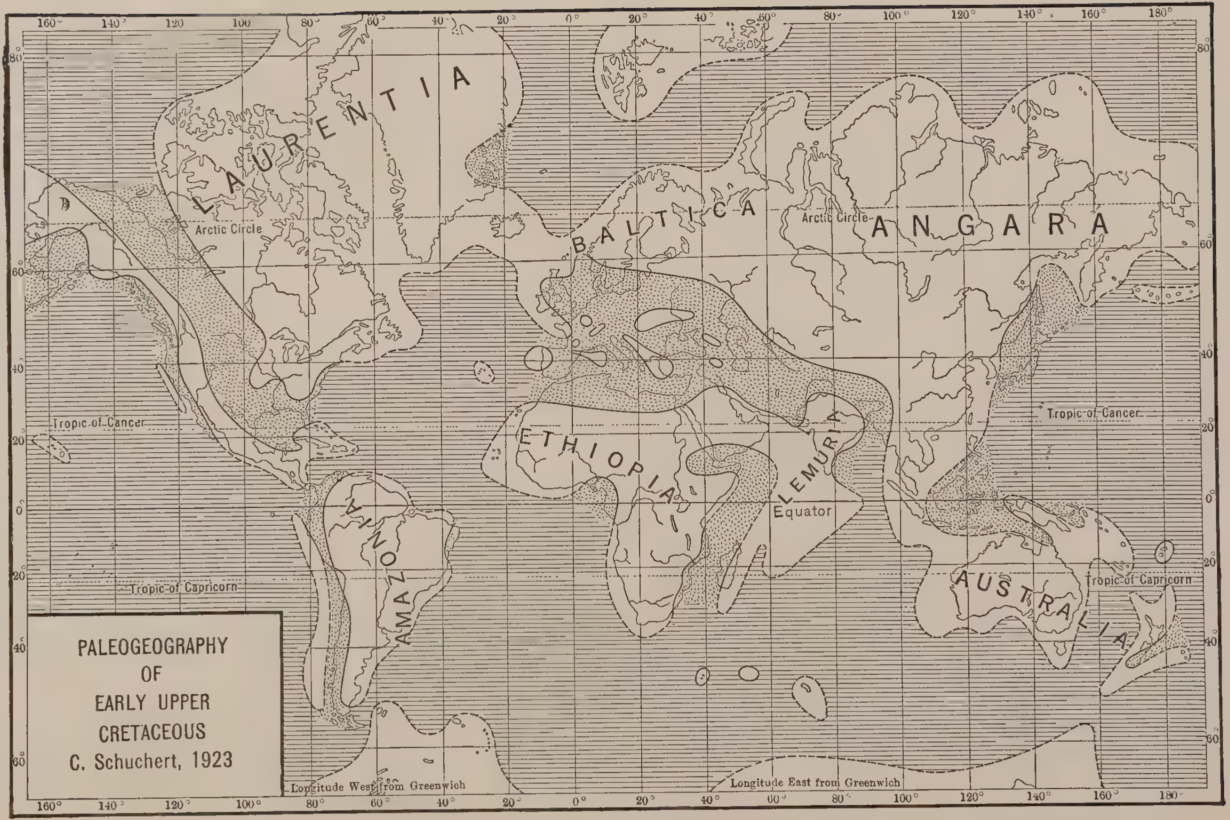


FIG. 55. — The greatest known transgression (dotted) of the oceans (ruled) over the lands. The time is early Upper Cretaceous. Laurentia, Baltica, and Angara make the continent known as Holarctica. Between Eurasia and Africa lay the great ancestral Mediterranean, Tethys.

geologic time. Not only do the lands move up and down, but it is also now clear that the ocean bottoms are at times more or less in motion. For these reasons, the oceanic level in relation to the continents is inconstant, and the marine waters ebb and flow over the continents. The movement of the ocean waters may be of small and narrow extent, due to local warpings of the surface, or may spread over areas of great magnitude, in consequence of marked crustal deformation and the filling of the oceans with land detritus.

It is now known that the oceans have spread repeatedly and more or less widely over the North American continent at least twenty times. In a broad way, it may be stated that the floods begin and end with shelf seas marginal to the continent and occupying between 1 and 5 per cent of the total areas of the continental platforms, the conditions thus being not unlike the present conditions of overlap; while the greatest inundations are of the interior or epeiric seas that cover from 12 to about 50 per cent of the continent. There is a certain amount of rhythm in these movements, and this has been used, as will be shown later in this chapter, to divide the geologic sequence into systems of rocks or periods of time.

As the oceans and seas are all connected one with another, and are also the receivers of most of the land wash, it follows that a displacement of the strand line anywhere, through any cause, must be transmitted to all marine waters. It has been calculated that if the present higher land masses were transferred to the oceans without crustal disturbance, the general sea-level would be raised about 725 feet, and therefore much of the North American continent would be flooded.

Under the waters there is continuous sedimentation, and they abound in more or less of evolving life that is most advantageously situated for burial and preservation; hence the marine stratigraphic sequence is the least broken of the several kinds of historic records accessible to geologists. It is therefore apparent why the major portion of the Earth's chronology depends for its determination upon the marine sediments. These sediments, except in so far as they are later eroded, record the extent of the transgressions, and their physical character, something of the topographic form of the adjacent lands, with a hint as well of their climates; and through their fossils they establish not only the chronology from place to place, but the sequence of time everywhere on the Earth as well.

The Major Geologic Features of North America

When the geologic history of the North American continent is viewed as a whole, it becomes apparent that there are certain crustal elements that have played fairly constant rôles; in other words, parts of the continents have been persistent areas of elevation (positive areas), and other parts have as persistently been depressed (negative areas). In a broad way, we may say that the continent consists of (1) a very ancient positive area, or shield; (2) persistent seaways, or geosynclines, which lie, roughly, around the positive areas; (3) recurrently rising borderlands, situated between the geosynclines and the oceans, which are much more unstable areas than the shields but for the most part stand above the seas. In addition, there are (4) much smaller areas of persistent elevation, the geanticlines, where the crust is bowed up rather than folded as in the areas of the mountains. These major crustal elements will now be discussed in more detail.

Positive Areas of Interior North America (study Pls. 1–4). — The interior basin portion of North America has two large areas which have been but little invaded by marine floods. The larger is the Canadian Shield (Fig. 42), already described in Chapter VIII. The other, far smaller, persistent area is *Siouia* of the present Great Plains country, which came into existence late in Proterozoic time as a highland, was encroached upon by the interior seas of the Paleozoic, and almost completely flooded during Pennsylvanian time. To-day Siouia, though highly elevated, is deeply buried beneath Mesozoic and later formations. Another, but small, positive area of Paleozoic time is *Ozarkia* in the state of Missouri.

Negative Areas or Geosynclines (study Pls. 1–4). — As a result of work in the Appalachians and other mountain regions, geologists long ago saw that mountains occur chiefly in areas of greatest sedimentary accumulation. The rock formations in the Appalachian region are, for example, possibly ten times and certainly six times thicker than the equivalent deposits of the same seas in the Mississippi Valley. These thick sediments we now know were accumulated in narrow troughs or synclines that persisted as shallow seaways for long periods of geologic time. Such troughs were the most unstable areas of the Earth's crust, and it was their sinking as sedimentation progressed that made possible the accumulation of sedimentary rocks to such great depths as 5 to 8 miles. After sinking through tens or even hundreds of millions of years, these areas eventually rise, and comparatively quickly, into fold mountains, and then are re-elevated time and again. These unstable areas are called *geosynclines*. (See also pp. 327–328 of Part I.)

The oldest of the North American geosynclines are (1) the *Appalachic-St. Lawrencic*, in the eastern part, trending northeast-southwest; (2) the *Acadic*, in sympathetic relation with (1); (3) the *Cordilleric* and (4) the *Pacific*, in the west, each with a north-south axis; (5) the

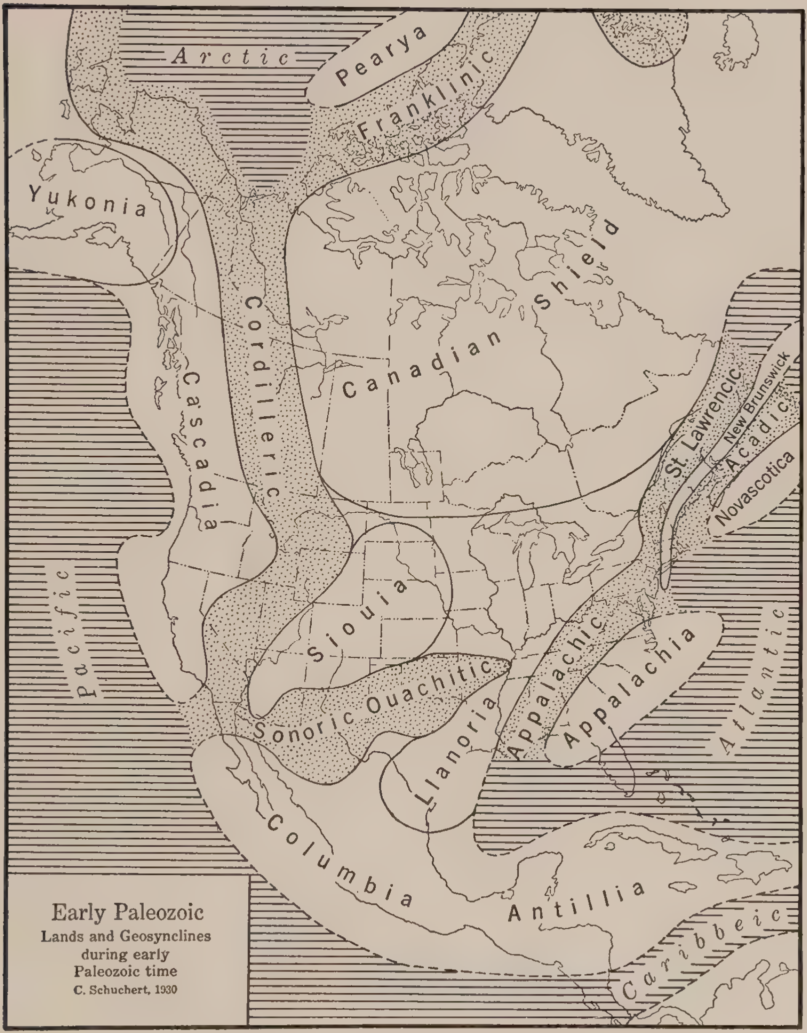


PLATE 2. — The North American borderlands (Cascadia, Columbia, Appalachia, and Novascotica) and geosynclines (Cordilleric, Franklinic, Sonoric-Ouachitic, Appalachic-St. Lawrencic, and Acadic), during Cambrian and Ordovician times. In the east is the New Brunswick geanticline. Other lands are the Canadian Shield, Pearya, Yukonia, Siouia, Llanoria, and Antillia. Also note the Caribbeic mediterranean. Compare Plate 3.

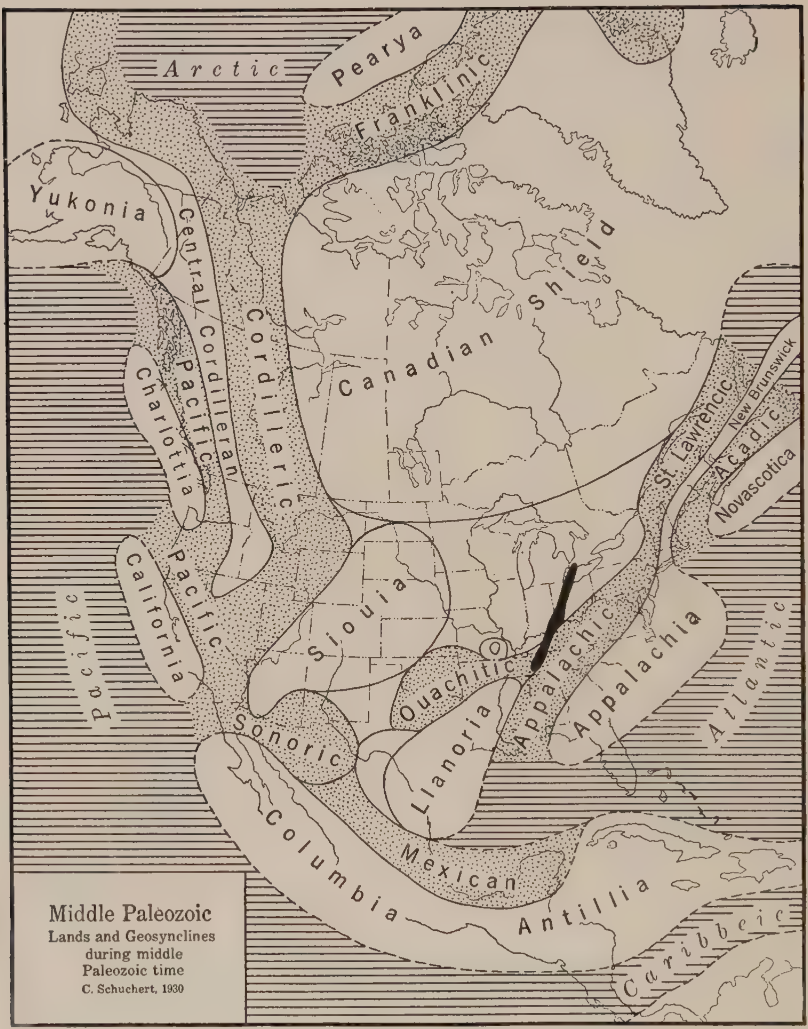


PLATE 3. — The North American borderlands (California, Charlottia, Columbia, Appalachia, and Novascotica) and geosynclines (Pacific, Cordilleric, Sonoric-Ouachitic, Mexican, Appalachic-St. Lawrencic, and Acadic) during Silurian and Devonian times. In the west is the Central Cordilleran, in the east the New Brunswick, and in Ohio the Cincinnati (black) geanticlines. O = Ozark dome. Other lands are the Canadian Shield, Pearya, Yukonia, Siouia, Llanoria, and Antillia. Also note the Caribbeic mediterranean. See Plate 2.

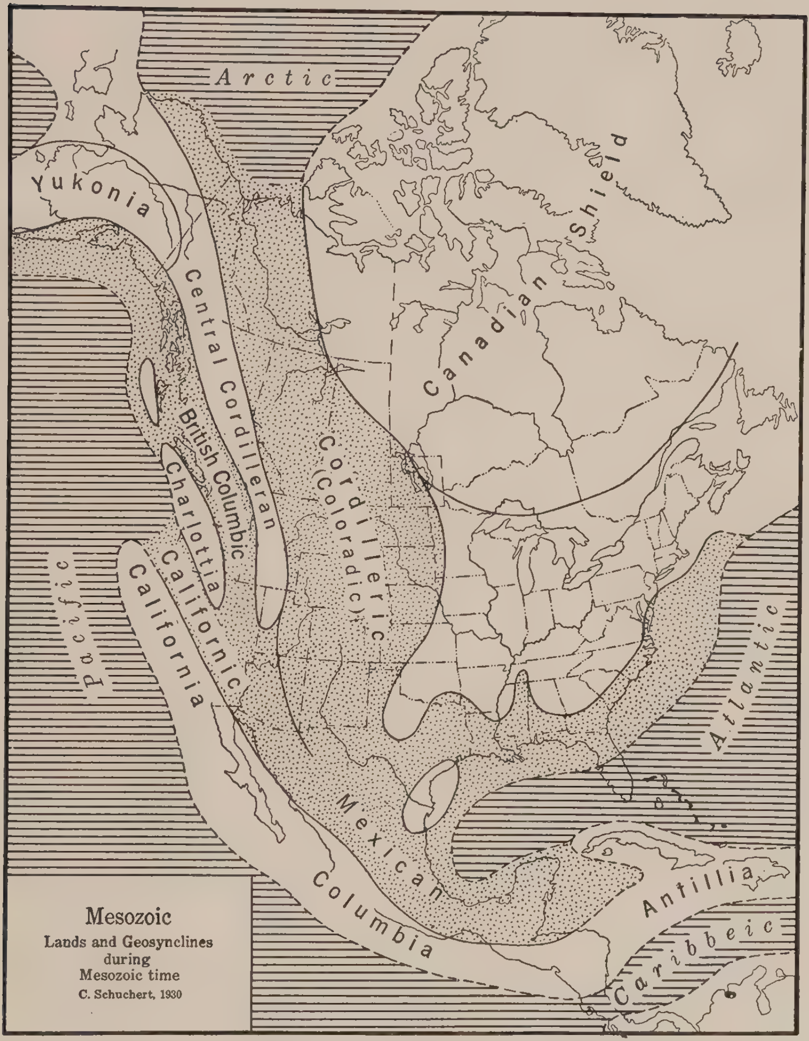


PLATE 4. — The North American borderlands (California, Charlottia, and Columbia) and geosynclines (British Columbic, Californic, Cordilleric, and Mexican) during Mesozoic time. In the west is the Central Cordilleran geanticline. The wide Gulf and Atlantic shelf sea is present only during Upper Cretaceous time. Note the Caribbeic mediterranean.

Ouachitic-Sonoric, in the south, striking somewhat northeast; and (6) the *Franklinic*, in the Arctic, with a northeast-southwest trend. A glance at the maps will show that these subsiding geosynclines surround the great central and more or less positive masses of the continent. The St. Lawrencic trough, and the Acadic, were converted into mountains in the middle of the Paleozoic era (Devonian), while the Ouachitic-Sonoric, Franklinic, and Appalachic rose into mountains toward its close, leaving only the Cordilleric and Pacific to continue into the Mesozoic era.

During the Mesozoic, still other geosynclines came into prominence; they originated earlier, but their Paleozoic history is obscure. These are: in the western part of the continent, the more or less confluent *British Columbic* and *Californic* troughs, which are continuations of the Pacific geosyncline of Paleozoic time; and, in the far south, the *Mexican* geosyncline. The history of these troughs will be made clear in later pages.

Borderlands (study Pls. 2–4). — The accumulation of vast thicknesses of sediments in a geosyncline presupposes the existence, at no great distance, of highlands from which the eroded rock material could have been brought down by streams and delivered into the waters of the trough. These sources of sedimentary supply, the borderlands, were situated outside or oceanward of the geosynclines, and were repeatedly raised into highlands, though they never appear to have been folded while the troughs on their inner sides were subsiding. They probably were faulted and tangentially sliced and thrust toward the geosynclines while the troughs were sinking, but this action seems to have taken place mostly during the times when the geosynclines were being folded into mountains.

The borderlands formerly extended an unknown distance out into the oceans. From the quantity of sediments that they have furnished to the geosynclines, it is certain that they continued beyond the present strand lines at least 200 to 300 miles, and some of them doubtless considerably further. The quantity and nature of the sediments derived from them indicate something of their extent and the times of their periodic elevation.

North America was margined on the east by the borderlands *Novascotica* and *Appalachia*, each one of which had its own geologic structure and history. Along the west coast was the greatest of all the borderlands, *Cascadia*, which later divided into *California*, *Charlottia*, and *Columbia*. To the northwest of the Gulf of Mexico was *Llanoria*. Finally, arctic America was bordered by *Pearya*, part of which is now elevated, along with the Franklinic geosyncline, into the folded United States Mountains. It has been the fate of the North American borderlands to vanish almost entirely by downwarping and faulting into the depths of the oceans: little of Novascotica is left as land, and most of it makes the fishing banks of the North Atlantic; remnants of Appalachia remain as the Atlantic coastal plain and the piedmont back of it; along the Pacific, nearly all of Cascadia has gone deeply into that oceanic basin.

Geanticlines (study Pls. 2–4). — Geanticlines are the broad upward bowings in the Earth's crust, and differ at once from the common type of mountains in that their rocks were not folded during the time of elevation. The *Cincinnati geanticline* (often called the Cincinnati arch), the best known of these upward bowings, is a wide flexure in the Earth's crust centering near the cities of Cincinnati and Nashville. Its width is something like 250 miles, and it was in various places completely overlapped by the interior epeiric seas. The *New Brunswick geanticline* includes the granitic area of eastern Connecticut and Rhode Island and the White Mountains of New Hampshire, striking across central Maine into northern New Brunswick and southern Newfoundland.

During the Mesozoic, the greatest of all North American geanticlines, the *Central Cordilleran,* lying between the Pacific (British Columbic-Californic) and Cordilleric troughs, played a major rôle in the geologic history of the West. It is discussed in more detail in Chapter XVII.

The Making of Paleogeographic Maps

Like geography, paleogeography records its findings on maps, but unlike the former science, the latter one does not make its own base maps but is obliged to draw its results over the geography of our own time. This method distorts the true relation of the parts one to another more and more the further we go back into geologic time. This distortion is due to the foreshortening in all places where fold mountains occur, as a consequence of which the present geographic base map gives a more or less erroneous picture of the actual size and shape of the ancient lands and seas. At present, however, this distortion can not be avoided. Moreover, paleogeographic maps are as yet mainly concerned with plotting the transgressions of the shallow seas over the continents, and in picturing in a general way their outlines and extent within a limited geologic time; the more limited this time is, the more truthful the map will be, but the more difficult to make because of the lack of detailed stratigraphic knowledge.

In the actual making of a paleogeographic map of a given time, the first step is to plot the known occurrences of the rock formations of that time. This will indicate in general the area covered by the invading seas, but may still leave undecided such questions as the direction from which the sea entered upon the continent, where its shorelines lay, whether or not there were positive areas left unsubmerged as islands, peninsulas, and so on. To find the answer to such questions, the paleogeographer turns to a more detailed study of the rocks themselves and particularly of their included fossils. The nature of the rocks, for example, tells whether they were formed in water or by the winds, in seas or oceans or in rivers and lakes, or on dry lands under pluvial or arid climates; also the probable depth of water in the seas, the amount of agitation, and whether deposition took place near to, or far from, shore. To be more specific, and keeping in mind the fact that streams carrying sediments into the seas deposit the coarser material first and the finer and finer as they go farther out into the marine waters, it is evident that coarse sandstones passing laterally into conglomerates indicate that the shore lay in the direction of the coarsest material. Thick fine-grained rocks, on the other hand, such as the calcareous mudstones and the limestones and dolomites, would be deposited in general away from the shorelines of highlands, in the deeper and quieter parts of the seas; but where the lands are low, as in the peninsula of Florida, the marls may be accumulating at the shore, with the limestones farther out. There are many exceptions to these general rules of deposition, and all that is here intended is to show the broad principles that guide the paleogeographer in his interpretations.

Further guidance in the matter of shorelines is had in the knowledge that certain parts of the continents are more positive than others, *i.e.*, have a local tendency to rise more or less frequently and to variable heights. Such, for instance, are the shields and related areas, borderlands and geanticlines, spoken of earlier in the chapter. For these periodically rising areas the paleogeographer is ever on the lookout, since they indicate to him the probable position of the dry lands, hence also of the shorelines, and the sources from which the sediments were derived and delivered into the seas.

To locate the *actual* position of the shorelines of the ancient seas is, however, not an easy matter; in paleogeographic maps of small scale, the best known of the shorelines are probably almost always in error anywhere from 5 to 50 miles. This is largely due to the fact that the shore deposits are nearest the borderlands and accordingly are the first to be eroded away.

One of the greatest difficulties in making paleogeographic maps is encountered in areas where the formations at the surface go beneath younger ones and do not reappear on the other side of the basin of deposition. Even more deterrent are the great lava fields, as for instance those of the Columbia and Snake rivers, which cover at least 150,000 square miles of older strata; or the regions of great batholiths, such as the one of the Coast Range of British Columbia, where the older formations have been swallowed up or metamorphosed beyond recognition by the igneous masses, or have been eroded away since their rising. In all these areas one is dependent in his studies upon the distribution of the formations with synchronous faunas.

For information as to the direction from which the seas invaded the continents, and their connection with other seas, the paleogeographer turns to a study of the fossils buried in the marine formations; since fossils, in addition to dating the rocks, have much to tell about the environment in which they lived, whether in the seas or oceans, on lowlands or highlands, in swamps, rivers, or lakes, and whether the climates were cold, temperate, or tropical. Normally marine deposits have an abundance and variety of bryozoans, brachiopods, echinids, crinids, and cephalopods; if the seas are warm, they have also reef-building corals, thick-shelled bivalves, large foraminifers, and many cephalopods; but in brackish waters nearly all these marine types are absent. Nearshore seas have oysters and barnacles; cold waters have faunas that are abundant in individuals but poor in variety, and so on.

Thus, if marine invertebrates known only to live in cold waters are found in rocks of the Miocene as far south as Alabama (Chesapeake formation), the seas that buried them there had cool waters flowing south along the continent from the far north. Conversely, when shallow-water and reef-making corals of the Gulf of Mexico type are found about Carrizo Creek of southern California, naturally their source must have been the Mexican Gulf. Again, when characteristic North European species or genera are found in Illinois, or South European ones in Oklahoma and Arkansas, we must postulate seaways in the appropriate regions to bring them into the places of their burial in North America.

Another check on the position of the seas is the fact that they lie as a rule in the sinking troughs or geosynclines, although the widest transgressions spill outside of these, and cover great areas in the interior basin of the continent. Once these troughs are folded up into mountains, however, they have a tendency to be re-elevated time and again, and therefore to remain as continuous lands. It is rare to find places where the oceans have spread completely across the site of a Paleozoic mountain range, or one of younger age, but it is not so rare to find that Paleozoic or younger seas have spread completely across mountains of Proterozoic or Archeozoic time. A most wonderful transgression of this nature is to be seen at Bright Angel on the brink of the Grand

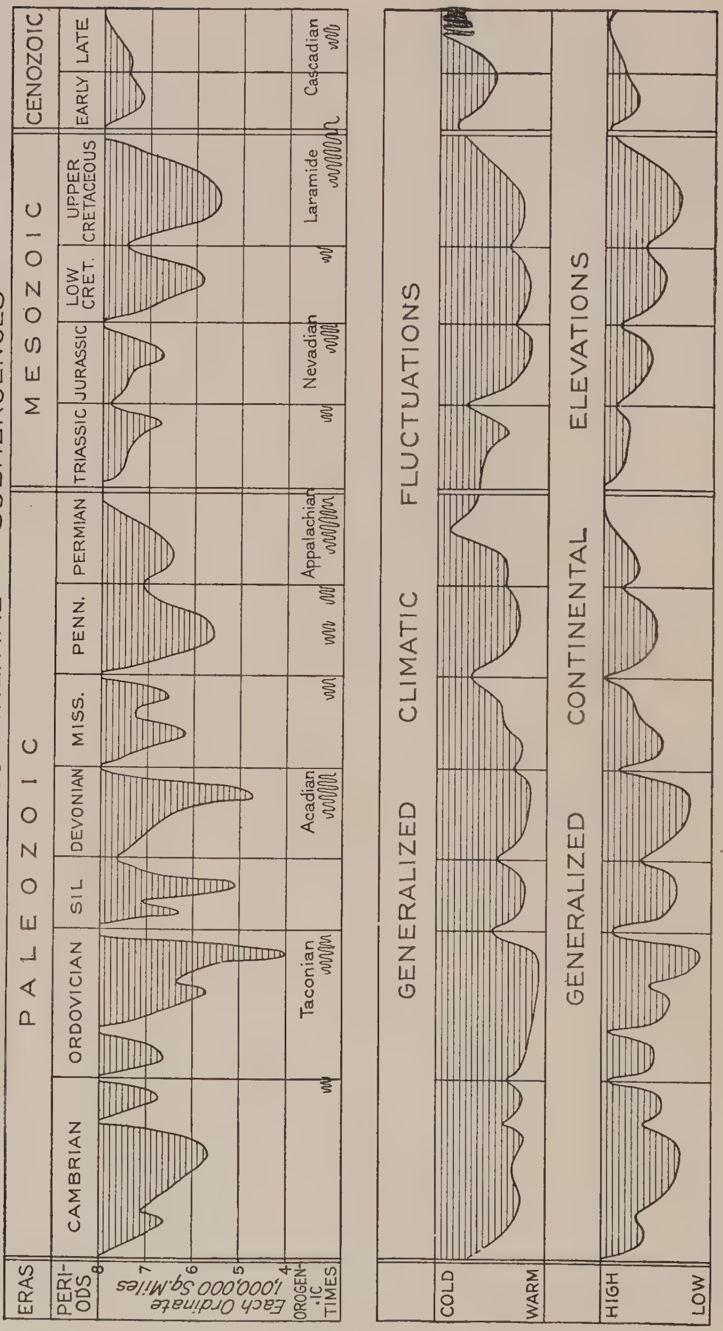


FIG. 56. — Diagram to show the times of continental flooding and their extent in millions of square miles; the times of mountain making; and the degree of continental elevation and climatic fluctuation.

Canyon of the Colorado River (see Fig. 49), where Cambrian seas have spread horizontal strata across the upturned and worn-down roots of mountains that were uplifted at different times during the Archeozoic and Proterozoic.

North American Paleogeography. — Turning now to the paleogeography of our own continent more particularly, we know, as already stated in Chapter II in abbreviated form, that North America has been more or less widely flooded by the oceans at least twenty times, and that these shallow-water floods varied in extent between 150,000 and 4,000,000 square miles. At times there were vast inland seas, many of them far greater in areal extent than the present Hudson Bay. These facts show how constantly the geography of the geologic past has been changing. To-day we are living in the first phase of a new cycle and a new era, and the oceans have already begun their spread over the continents, as seen in Hudson Bay, the North and Baltic seas, and in the more or less wide extension of the shallow seas over the shelves that border all continents.

Long study has shown that these floods are recurrent, and this fact, together with the advances shown in the life of the time, has been used in delimiting the smaller divisions of the geologic time-table, the periods, and their subdivisions, the epochs. A typical period (see Pls. 5, 6) has one major flood, usually toward the middle of its time duration, preceded and followed by smaller seas and an emerging continent. In other words, it begins with highlands, or at least with emergent conditions, constituting the first or earliest epoch (*e.g.*, Early or Lower Devonian), followed by a longer epoch when the sea invasion reaches its maximum (*e.g.*, the great Portage flood of Upper Devonian time), with the widest distribution of similar rock formations having more or less similar faunas and some identical species known as guide fossils. These middle submergences come on very slowly, spreading more and more in an oscillating manner until the climax is reached. The third and last epoch (*e.g.*, Late or Upper Devonian) witnesses the retreat of the seas, which goes on far more quickly than their advance. The reversal of crustal conditions, which brings the lands above the sea, is brought on by (1) mountain making, (2) continental elevation, or (3) deepening of one or more ocean basins, causing the lands to be more emergent. The last epoch is therefore one of predominant land conditions, though considerable areas in the geosynclines may continue to have localized seas, as they did in the first epoch. Moreover, there is a marked variation in the marine faunas and these are dissimilar in the various areas because the smaller seaways are then not connected with one another.

This idea of the ebb and flow of a single flood constituting a period

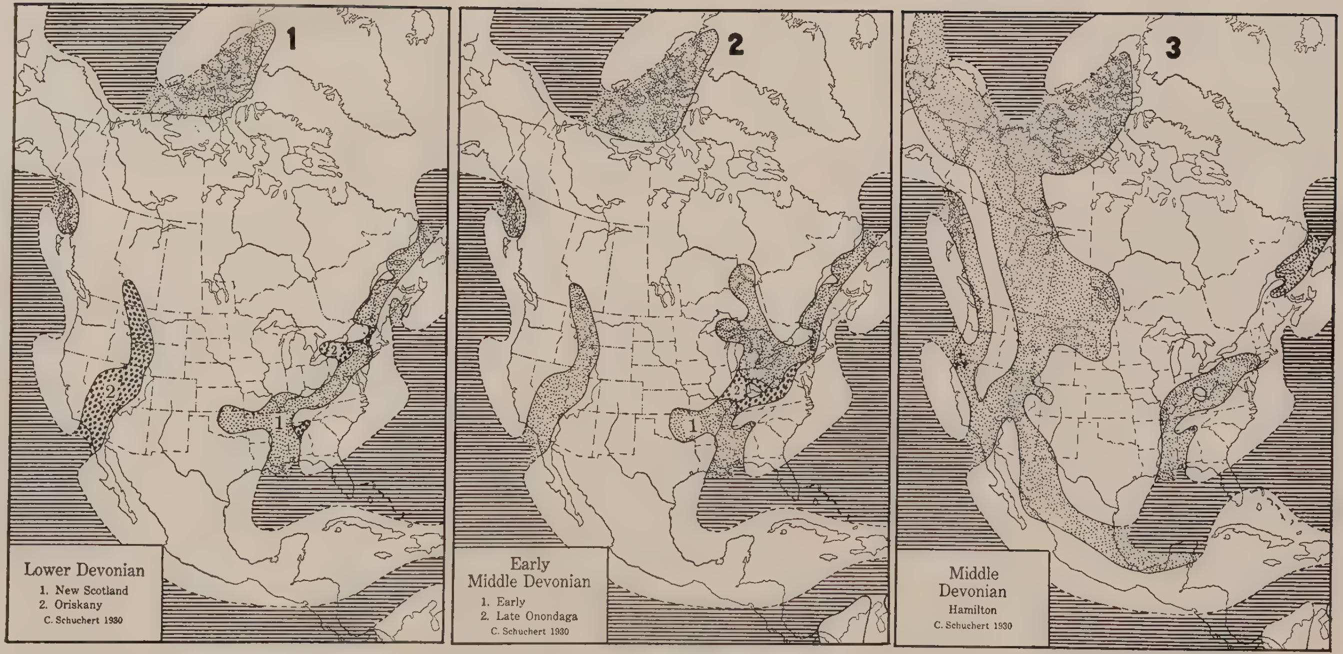


Plate 5. — Paleogeography of Devonian time.

Epeiric seas dotted; oceans ruled. Volcanic regions indicated by crosses.

The Devonian period is one of the best illustrations of a diastrophic cycle, occurring between the Caledonian orogeny of western Europe and the Acadian mountain making of eastern North America. Note the progressive but very slow spread of the oceans from the four quarters over North America until they unite to make one of the several largest floodings. The waters from the Arctic and Pacific brought Asiatic faunas (see Maps 3, 4, 5); those from the Atlantic spread European ones in part, though in the main the eastern faunas were American in development. Note the first appearance of the Mexican geosyncline (Map 3). See Plate 6.

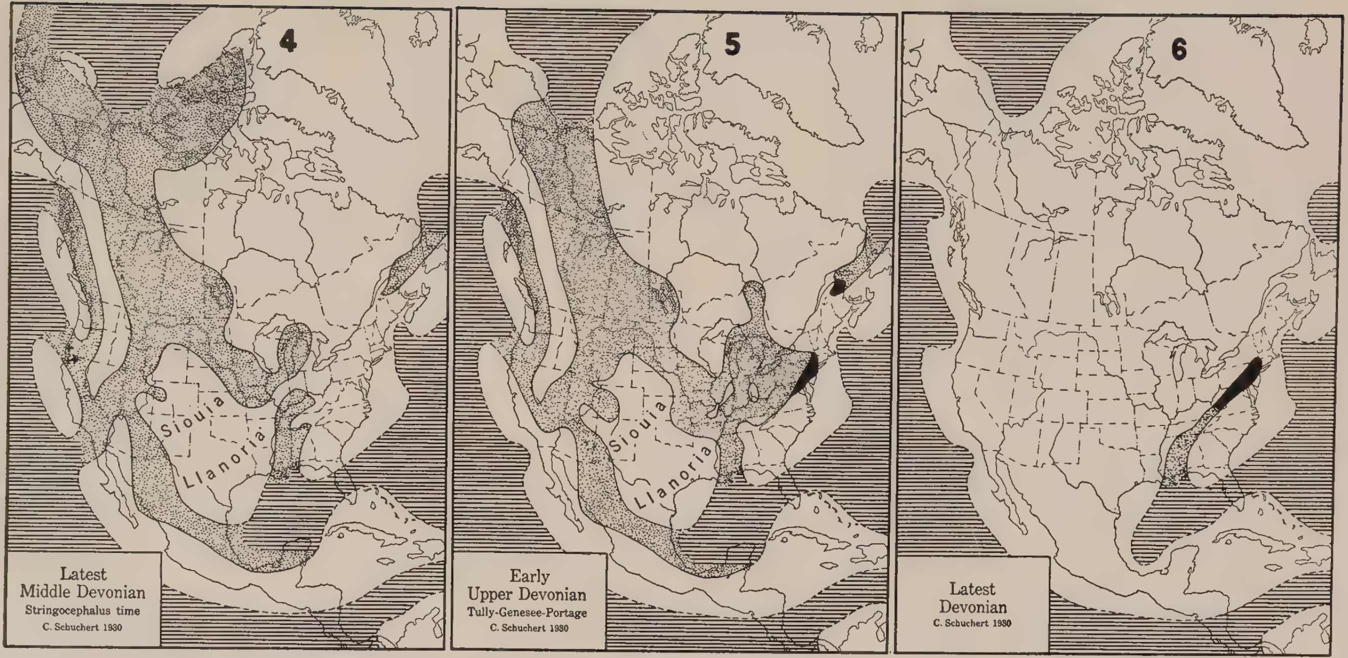


Plate 6. — Paleogeography of Devonian time (*con.*)

Epeiric seas dotted; oceans ruled; deltas in black (Appalachia and Gaspé). Volcanic regions indicated by crosses. See explanation of Plate 5. Note the persistent lands Siouia and Llanoria.

does not, however, always hold good. It is true for the Devonian and Pennsylvanian; the Silurian and Mississippian each have two floods of considerable extent; while the Cambrian and Ordovician each appear to have three submergences, all more or less widespread. It is clear that the Silurian as now defined is a natural period, but the other three appear to call for a redefinition into two or three periods each; in these latter cases we have to depend more on the emergences than on the floodings.

In regard to the length of time consumed by these flood cycles, there is no regularity among the periods and the epochs likewise have very dissimilar durations. As indicated by radioactive minerals, the periods as now defined vary in length from about 20 to 100 million years each, the two longest ones being the Cambrian and Ordovician; but when the principles of diastrophism and organic evolution are fully applied, their lengths will be between 20 and 45 million years each, and instead of the present seven periods in the Paleozoic there will be from ten to twelve.

CHAPTER XI

EARLY PALEOZOIC TIME: THE AGE OF MARINE INVERTEBRATES

THE PALEOZOIC ERA IN GENERAL

In the previous chapters we have studied the older, or least known, geologic history of the Earth, namely, that of the Archeozoic and Proterozoic eras. The pioneer geologists could not have had the faintest notion of the tremendous length of this Pre-Cambrian time, nor did their successors in the nineteenth century have a proper appreciation of its duration. It was only during the present century that geologists began to say that there may be as much geologic time back of the Paleozoic as subsequent to it, and now on the basis of radium disintegration we increase this Pre-Cambrian proportion to two-thirds. Accordingly all of the geology based on fossils, the greater part by far of what geologists and paleontologists know, covers only the last third of geologic time, or something like 500 million years. Nevertheless, the story yet to be told, dealing with this lesser portion of Earth history, is not only more interesting but better documented than that which has gone before.

Upon the very ancient rocks of Pre-Cambrian times rest, usually in marked unconformity, the abundantly fossiliferous strata of the Paleozoic era. A century ago, geologists in general held that these rocks contained the evidences of the first life that appeared on the Earth. Accordingly Professor Sedgwick of Cambridge University in 1838 named the lower part the Paleozoic series, the name meaning *ancient life.* Since then, however, as previously shown, we have learned that fossils do occur in Proterozoic strata and lime-secreting algæ even in those of the Archeozoic. Nevertheless, the term Paleozoic is now retained, not only for the part defined by Sedgwick but for all of the time and rocks between the Proterozoic era and the Mesozoic era. The Paleozoic is thus at present regarded as the third geologic era in the history of the Earth, or the third volume in the book of geologic time. Radioactive minerals indicate the length of this time to be of the order of 330 million years.

With the beginning of Paleozoic time, the abundance of fossils furnishes a ready means of correlating the formations not only from place to place but even between continents. Hence we have in most post-

Proterozoic strata a far more detailed knowledge of the sequence of events, leading to a determined classification of the strata, and also a greater knowledge of the two parallel evolutions, that of the rocks and that of the fossils.

Paleozoic of North America. — North America is wonderfully rich in a long succession of Paleozoic formations that abound in fossils, and this is more especially true for the eastern half of the United States and Canada. No other continent is so rich in this history, and over vast areas west of the Appalachian Mountains the highly fossiliferous strata lie almost as they were deposited, although of course much consolidated and hardened by time. When these strata weather away, they yield their entombed organisms freely.

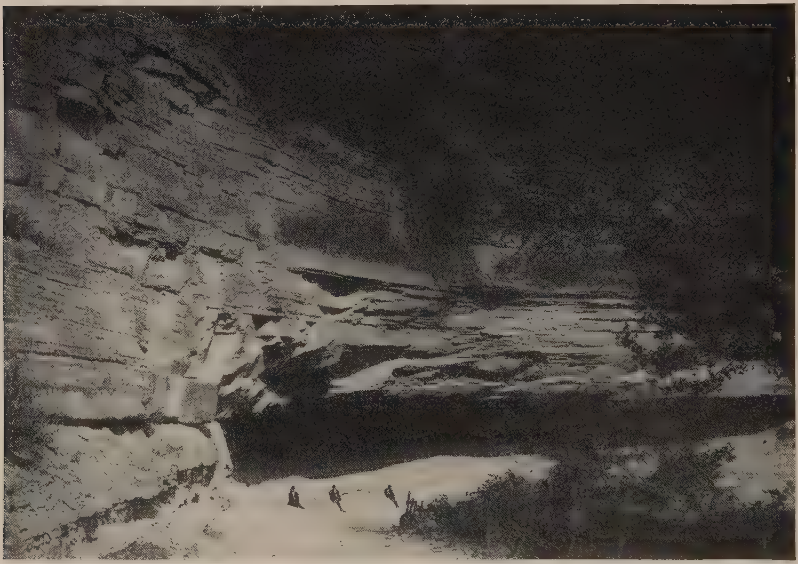


FIG. 57. — Horizontal limestones of Upper Ordovician time in the Mississippi Valley. Hanging Rock Falls, near Madison, Indiana. Photograph by H. McFlora.

Over the eastern interior of the United States and medial Canada, which is a vast basin of plains and low plateaus, the Paleozoics lie in nearly horizontal attitude. Toward the eastern part of this basin they change from horizontality into broad undulations and then rise more and more into the folded and faulted area of the Appalachian Mountains. On the western side of the basin, from an average elevation of about 500 feet above sea-level at the Mississippi River, the undeformed strata have risen to 1000 feet at Omaha, and on the High Plains they are over

5000 feet above the sea and in low undulations. In the Rocky Mountains and west to the Pacific Ocean the Paleozoic formations are all deformed in this very wide and mountainous land forming the Cordillera (see Fig. 59).

Divisions of the Paleozoic. — The units of geologic classification are the formations, just as the species are the units of the groupings in Biology. The formations are arranged into systems of rocks which represent periods of time, as was shown on page 11. At times, however, it becomes necessary for purposes of reference to speak of larger subdivisions of the eras, and accordingly the systems or periods may be grouped into *ages*. For instance, the known life of the Early Paleozoic consists almost wholly of marine invertebrates, because the upward trend of organic evolution had not yet attained a greater complexity. We therefore call it the *Age of Invertebrates*, and contrast it with the time of the Middle Paleozoic, when fishes have come into being and which is called the *Age of Fishes*. Finally the Late Paleozoic introduces the first amphibians and land floras, and we recognize this fact by calling it the *Age of Amphibians* or the *Age of Coal-making Plants*. The era is closed by the Permian period, the transitional time between the Paleozoic and Mesozoic eras.

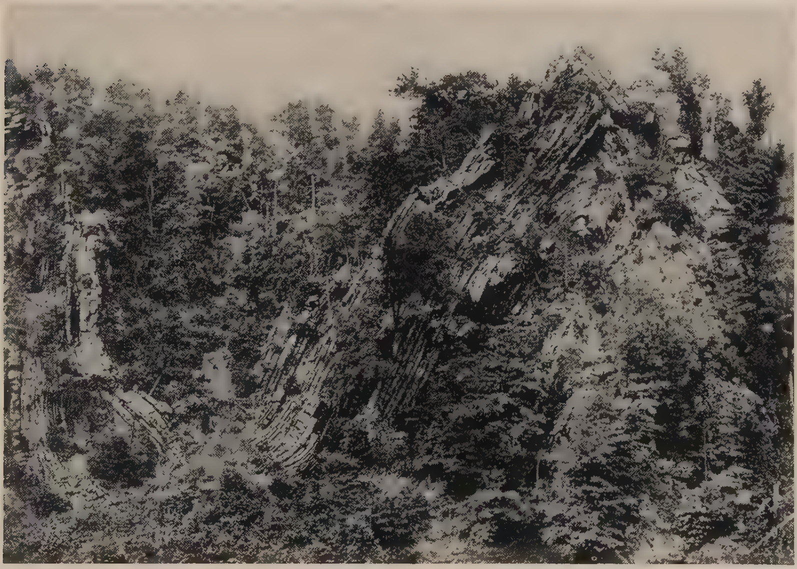


FIG. 58. — Thin-bedded limestones of Silurian age folded into anticlines and synclines during the making of the Appalachian Mountains. "Fluted rocks" on Great Cacapon River, West Virginia. U. S. Geol. Surv.

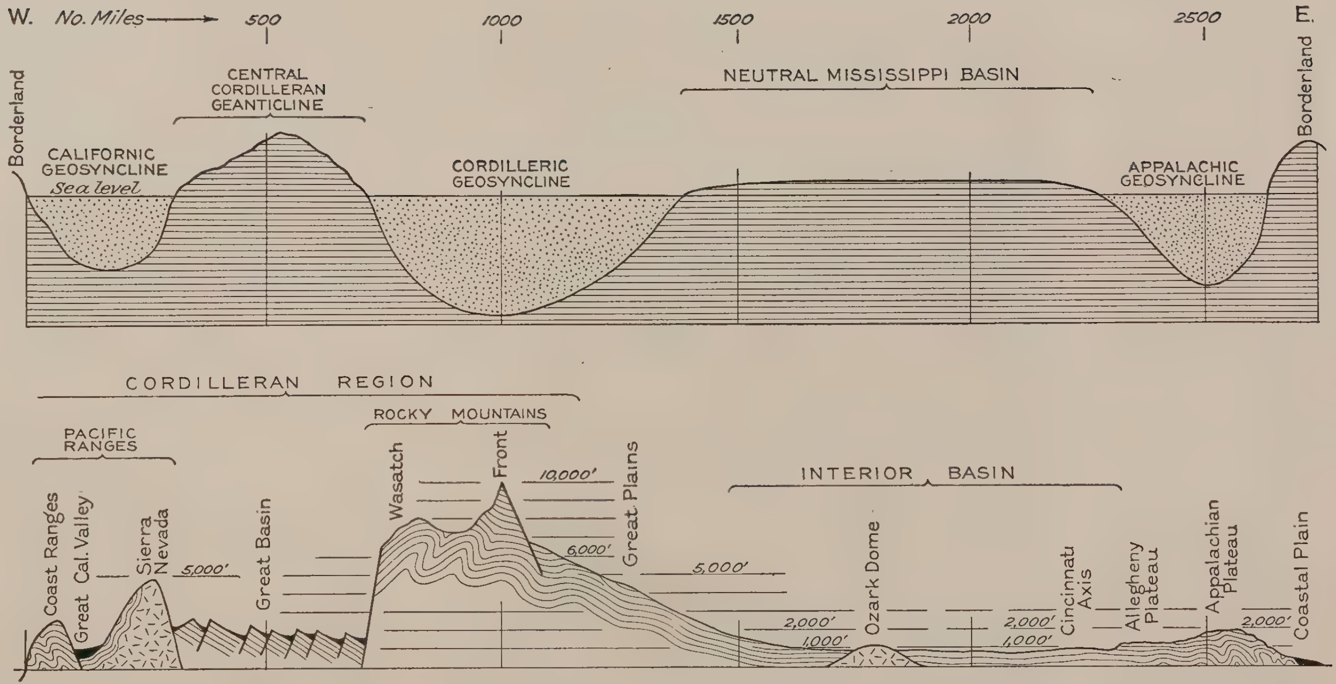


Fig. 59. — Greatly generalized diagram to illustrate the general structural relations of the lithosphere in section across the United States. Above, the places of the ancient geosynclines, geanticlines, and borderlands before the making of the mountain ranges. Below, the present geologic structure. Vertical scale much exaggerated.

The periods of the Paleozoic era as now widely accepted are the following, beginning with the youngest:

Late Paleozoic Age of Amphibians and Coal-making Plants	Permian (from the Perm District, Russia)
	Pennsylvanian (Pennsylvania)
	Mississippian (upper Mississippi Valley)
Middle Paleozoic Age of Fishes	Devonian (Devonshire, England)
	Silurian (Silures, a Celtic tribe of Wales)
Early Paleozoic Age of Marine Invertebrates	Ordovician (Ordovices, another Celtic tribe)
	Cambrian (Cambria, the Roman name for northern Wales)

EARLY PALEOZOIC TIME

Cambrian Geography

(Plates 7, 8)

At the very outset of the Paleozoic era, in earliest Cambrian time, the sediments show the presence of the two great north-south geosynclines or seaways that were already indicated in the Proterozoic. These were the Appalachic geosyncline in the east and the wider Cordilleric one in the west where the Rocky Mountains now are. The earliest known Paleozoic invasion of the sea came from the Pacific, which spread first into the Great Basin area and then crept northward in the Cordilleric trough, to unite finally with another sea that came in from the Arctic. To the west of this trough was the borderland Cascadia.

Shortly after the entrance of this western sea, a similar one appeared in eastern North America, laying down sediments in the Appalachic geosyncline, a narrow trough extending from Alabama to New York and thence, as the St. Lawrencic seaway, to southeastern Labrador and beyond to northwestern Europe. This Early Cambrian inundation, restricted to the western and eastern troughs, did not submerge more than 18 per cent of the continent.

As the seas spread into the Appalachic trough from the Gulf of Mexico, their waves broke to the east against a mountain tract, perhaps as grand as the present Sierra Nevada. These were the *Ocoee mountains* (see Pl. 8), the presence of which at this time is unmistakably indicated by a thick mass of Early Cambrian sediments in eastern Tennessee and western North Carolina and Georgia. These beds, the Ocoee group, cover a known area over 200 miles long by 30 miles wide, and vary in thickness from 9000 to 13,000 feet. That the mountains from which this tremendous thickness of sediments came stood shortly to the

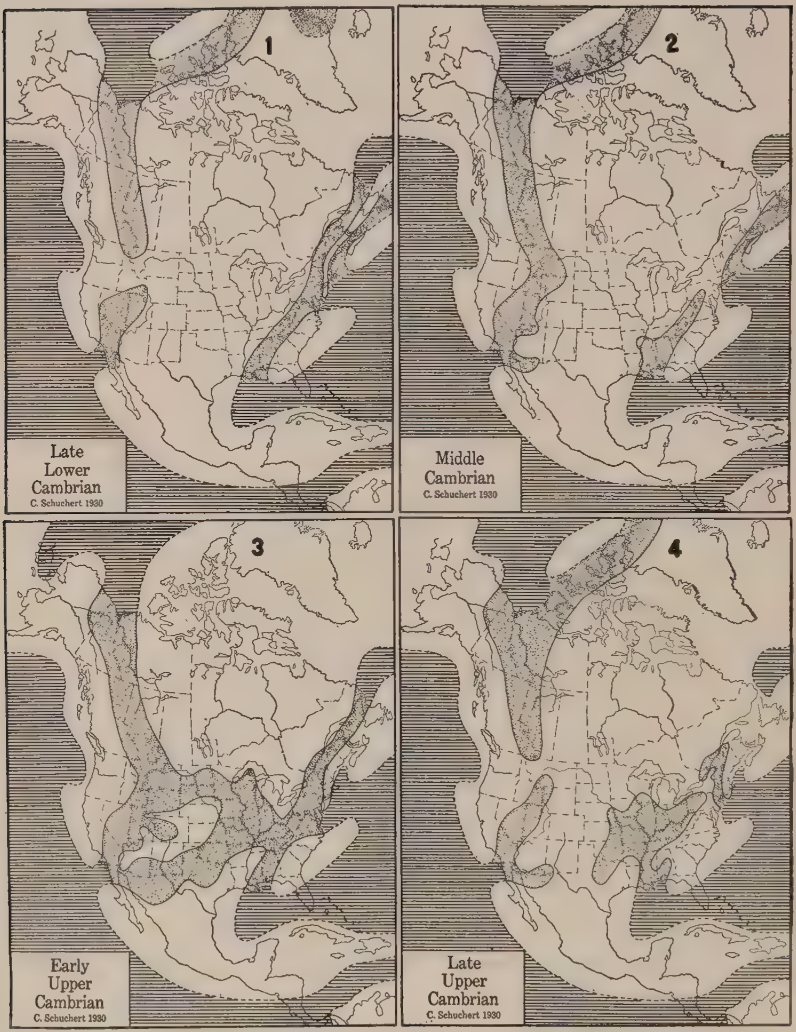


PLATE 7. — Paleogeography of Cambrian time.

Epeiric seas dotted; oceans ruled. See Plate 8 for Lower Cambrian physiography. Note that the Cordilleric, Appalachic, St. Lawrencic, and Franklinic geosynclines are in full development at this early time. The Acadic geosyncline had a sea in it in Lower and Middle Cambrian time.

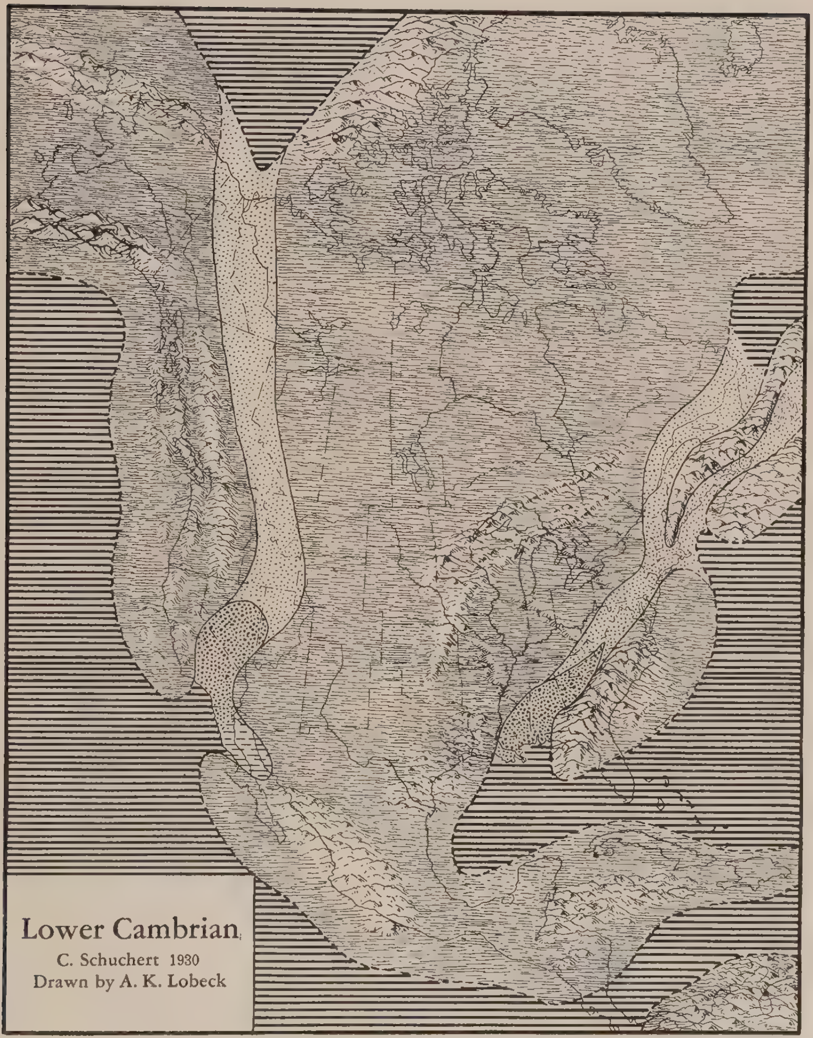


PLATE 8. — Lower Cambrian paleophysiography.

Epeiric seas dotted; oceans ruled; lands in wavy lines. See Plate 7 for Cambrian paleogeography.

The probable geography of Lower Cambrian time, without most of the drainage, which, is wholly unknown. Note the Ocoee mountains in Appalachia, and the Killarney mountains in Ontario-Wisconsin. The other mountain areas of this time are more or less hypothetic.

The land was devoid of all vegetation, and the climate mild and more or less arid.

east of where the deposits now lie is indicated by the fact that the beds thicken and become coarser in that direction. These mountains were presumably raised at the very close of the Proterozoic era.

The Ocoee mountains stood on the borderland of Appalachia, which lay outside of the Appalachic geosyncline and extended into the ocean hundreds of miles beyond the present shoreline. To the northeast of it was another borderland, Novascotica; and between the latter and the New Brunswick geanticline was the small Acadic geosyncline. These eastern marginal highlands furnished nearly all the sediments laid down by the procession of inland seas in eastern North America.

The Early Cambrian waters finally retreated, as we shall see each successive flood doing throughout geologic time. The Appalachic trough was drained of all of its marine waters, and stayed dry land for a much longer time than did the western one.

During the rest of the Cambrian most of North America appears to have been a lowland devoid of scenic beauty. Accordingly it was possible for the oceans to transgress the lands widely. If there were any highlands at all, they were in the bordering lands along the Atlantic and Pacific margins. In the center of the great interior lowland, however, stood a low upland consisting of the rumps of the Killarney mountains, made in Proterozoic time, which prevented the seas from spreading north of the Great Lakes (see Pl. 8).

The seas continued to fill the Cordilleric geosyncline through the rest of Cambrian time, and their persistence here resulted in the accumulation of great thicknesses of sediments. The combined Middle and Upper Cambrian of Utah reaches a thickness of 8500 feet; even more striking is the Cambrian of the Canadian Rockies, which has the vast total of 23,000 feet, 14,000 feet of this being Upper Cambrian (Warren). Certain of these beds are plainly to be seen on the sides of such landmarks as Mt. Stephen and Mt. Robson in British Columbia, where they were pushed up more than 10,000 feet above the sea in late Cenozoic time.

Late in the Middle Cambrian the western marine waters began for the first time to spread eastward through the Ouachitic-Sonoric trough, thence northward across the basin of the Mississippi Valley as far as the Great Lakes and eastward into the Appalachic geosyncline (Pl. 7, Map 3). Finally, in the late Cambrian the eastern trough carried the Gulf of Mexico waters northeast across Newfoundland and out into the North Atlantic. When this flood was at its height, about 30 per cent of North America was under its waters.

Ordovician Geography

(Plate 9)

At the end of the Cambrian the continent was completely emergent, since nowhere has there been determined an unbroken deposition from Cambrian into Ordovician formations. Until near the close of the Ordovician, however, it stood but little above sea-level, and only along its margins were there uplands. Hence the floods of this period were of great extent, in fact, the last one was more extensive than any other during the Paleozoic era. These great interior seas spread the warm oceanic water widely over the continent, and, as is usual under such conditions, limestones were the dominant rocks laid down. Ordovician time in general may well be spoken of as essentially one of limestone making.

The early submergences were restricted to the northeastern seaways (Acadic and St. Lawrencic), to the general Appalachian region, to the Mississippi Valley, and to the Cordilleric trough, with faunas peculiar to each region. At the close of early Ordovician time the continent was again completely emergent.

When the seas came back for the second time (Middle Ordovician) they again deposited limestones as before, but later on introduced more muds and fewer limestones because of the rising of the eastern borderlands. Moreover, the faunas are widely different from those of the Lower Ordovician. Therefore the usual insignificant break — the contact is everywhere merely a disconformity and not an angular unconformity — represents a loss of record long enough for the earlier faunas to have evolved into those so characteristic of the middle part of the period.

The middle portion of Ordovician time was one of markedly oscillatory and variable seas. Beginning again in the Ouachitic-Sonoric, Appalachic, and St. Lawrencic seaways, they spread into the Mississippi Valley but are as yet not much known in the Cordilleran region; their extent was not over 25 per cent of the continent. Their ebb left the continent emergent save for small overlaps in the south.

One of the interesting records of Middle Ordovician (Lowville) time is the occurrence of one or more ash beds from a few inches up to 7 feet thick, now known to occur all the way from Tennessee to Minnesota. Until these ash beds were discovered, no one had suspected that these light blue and almost unfossiliferous clays were of volcanic origin. It is thought that the ash came from the eastern borderland, but this is as yet unproved.

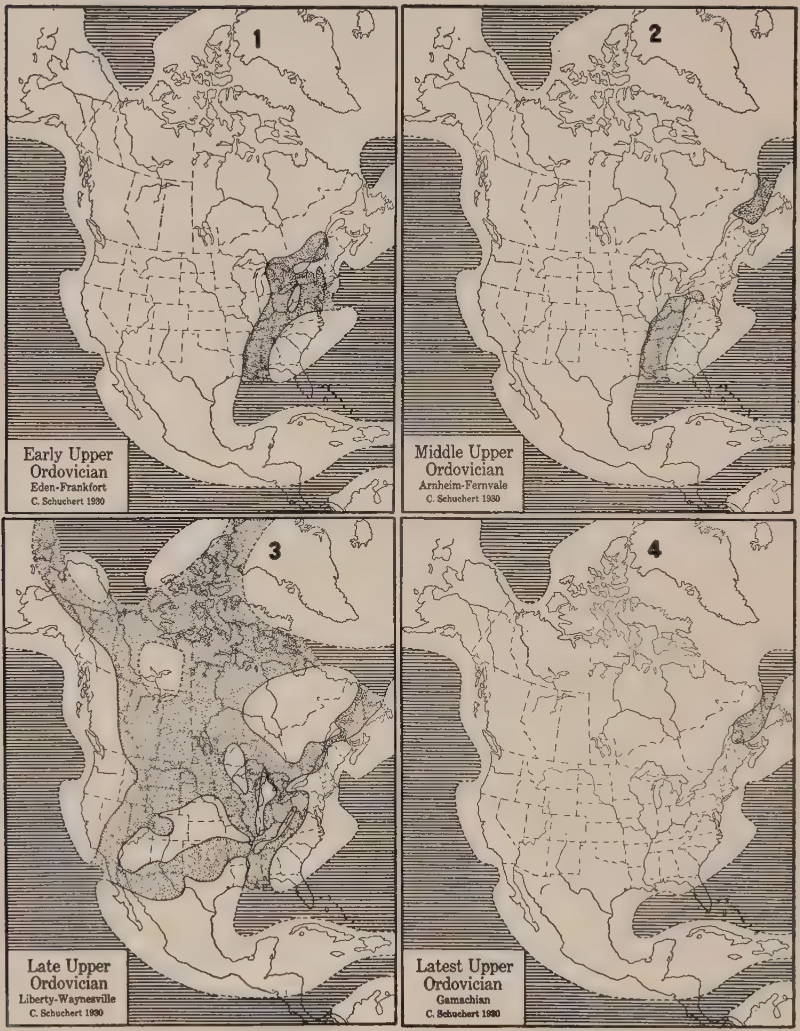


Plate 9. — Paleogeography of Upper Ordovician time.

Epeiric seas dotted; oceans ruled.

There were three separate floods in Ordovician time, but only the last and greatest one, mainly from the Arctic Ocean, is here illustrated. This, the Richmondian sea, was the most extensive transgression by the oceans that ever befell North America.

Again the seas came back over the continent, this time for the greatest flood of all. From the small southern areas they spread first north across Lakes Erie and Ontario and down the St. Lawrencic trough to east of Quebec City, where their sediments now reveal the southern and interior faunas. Over these sediments were laid others brought into the same area a little later by a wide flood from the Arctic and another up the St. Lawrencic trough from the Atlantic. Finally, Arctic, Atlantic, Gulf, and Pacific waters mingled to cover 40 to 50 per cent of North America, not only in the geosynclines but over most of the vast central basin. This was the great *Richmondian sea*, the widest known invasion of the continent, shown at its maximum on Map 3 of Plate 9.

From this survey of the paleogeography of Cambrian and Ordovician times, it is apparent that the seas were undergoing much change. This unrest in the hydrosphere was evidently due to the movements within the borderlands, not only depressing the geosynclines and elevating the borderlands, but affecting the general level of the strand line as well. The greatest mass of Cambrian and Ordovician sediments was laid down in the Cordilleric trough, amounting to over 25,000 feet in the Canadian Rockies and about 16,000 feet in the Great Basin area. In the Appalachic geosyncline the maximum sinking was over 15,000 feet in eastern Pennsylvania, and as much or more in the southern part of this same trough.

The history of the close of the Early Paleozoic (late Ordovician) in eastern North America, particularly in the areas where the floods entered from three directions and left the paleontologists a series of faunal riddles to disentangle, was further complicated by mountain making. This made the *Taconian mountains*, which began in eastern Pennsylvania near Lehigh, extended northeast through eastern New York and central Vermont where to-day are the Taconic and Green mountains, and continued northeast as the Notre Dame Mountains throughout southern Quebec and the Gaspé Peninsula; beyond this point they have not yet been traced. At this time either the whole of the New England States and the Maritime Provinces of Canada was moved to the northwest or the Canadian Shield pushed to the southeast, shoving into great folds and overthrusts the westernmost part of the St. Lawrencic geosyncline; the city of Quebec owes its commanding position to one of these great overthrust masses. What we see of these mountains to-day are re-elevations of the Taconian tract in late Cenozoic times, but their original grandeur may not have been much greater than that of the present Green Mountains.

By-products of this orogeny are the slates so extensively mined in Pennsylvania and Vermont, which are made by highly compressive forces acting on fine-grained mudstones; and the famous marbles of Vermont, which are metamorphosed limestones.

LIFE OF THE CAMBRIAN

In the chapter on the Proterozoic era we directed attention to the fact that among the organic remains back of the Cambrian not one fossil is known of an animal with an external calcareous skeleton. In the same place we speculated as to why the animals did not use lime for their skeletons, and saw that lime may not have been present in quantity sufficient for such use until Lipalian time, of which we unfortunately have no record. In any event, by earliest Cambrian time it had become the fashion in a number of phyla to wear external calcareous skeletons to protect organs and structures and aid in their development. This external skeleton or shell was developed as time went on into a still better and more efficient armor.

That some great change in the organization of animals took place after Proterozoic time, which ensured their preserval in the rocks, is at once apparent when we compare Cambrian life with that of the foregoing era. The Cambrian strata of North America alone have yielded at least 1200 different kinds of animals, in contrast to the very few known from the Proterozoic. The Proterozoic, moreover, gives us representatives of but three phyla (protozoans, sponges, and worm-like animals), whereas at the outset of the Cambrian five additional phyla — practically all the important ones — are in evidence (cœlenterates, molluscoids, molluscs, echinoderms, and arthropods). Nevertheless, although Cambrian life is primitive, it is not at all as simple structurally as would be expected; in fact, it is far from being the most primitive, since it ranges from simple sponges to complex forms of Crustacea, indicating a long evolution and the probable existence of the ancestors of these groups long, long before Cambrian time. Curiously, it is the higher phyla that are best recorded (trilobites, brachiopods, and gastropods).

When the richness and variety of Early Cambrian life was first brought out (1890) by Charles D. Walcott, the American authority on the life of this period, comment was made by the zoölogists that these forms, instead of being " the simple unspecialized ancestors of modern animals . . . are most intensely modern themselves in the zoölogical sense, and . . . belong to the same order of nature as that which prevails at the present day" (Brooks). This statement is all the more striking when we remember that at the time it was made there was no one who knew that three-fourths of geologic history, or 1000 million years, had already passed before Cambrian time was reached, and nearly all of it had evolving life! It therefore emphasizes all the more the extraordinarily long time it took for life to get started and to establish its various phyla of invertebrates; and how near to the present Cambrian time is, zoölogically speaking.

In detail, however, the Cambrian faunas did not in the least resemble the marine assemblages of to-day, not only because they were all of comparatively primitive life, but mainly on account of the abundance of stocks that are now either extinct or greatly reduced, and the presence in our modern faunas of stocks that have risen into a prodigality of form in no way predictable from their Cambrian ancestors. To-day the seas swarm with highly varied molluscs or shellfish and with true fishes, but during the Cambrian the shelled animals were insignificant in size and of small variety, and there were no stony corals, starfishes, or even the most primitive sort of fishes.

The dominant creatures in the Cambrian seas were the predacious and scavenging *trilobites* (page 59 and Pl. 10, Figs. 15–23), present in a vast variety and making up fully 60 per cent of the fauna. They are by far the most important fossils in the Cambrian rocks. There was also an abundance of them in the Ordovician, but they were then overshadowed by the brachiopods, bryozoans, and molluscs. In size, matured trilobites varied greatly; none of the Cambrian ones exceeded 15 inches in length — and at that they were the giant animals of the time! — but several of those in the Ordovician grew to 2 feet long. As a rule, however, they were small, ranging between 1 and 3 or 4 inches.

Next to the trilobites in importance came a horde of *brachiopods* (30 per cent of Cambrian faunas; see page 51 and Pl. 10, Figs. 2–8). The early and middle epochs have mainly the forms with phosphatic shells, and in places, chiefly in calcareous sandstones and thin flaggy limestones, and more rarely in shales, entire bedding surfaces are covered with them. In the Late Cambrian, the types with calcareous shells begin to strike out into prominence, and these are especially varied and common in the Middle and Late Ordovician. In the Ordovician the brachiopods branch out into the various phyletic lines that become conspicuous in the later periods of the Paleozoic.

Snails (gastropods, see page 55 and Pl. 10, Figs. 9–14) were scarce in the Cambrian, small, and not at all varied or beautiful, and of other molluscs there were hardly any. Other kinds of animals known as fossils were not significant in the economy of the Cambrian seas, but the *annelids* must have been common. Undoubtedly the *seaweeds* (algæ) were then as important as they are to-day, but not the slightest

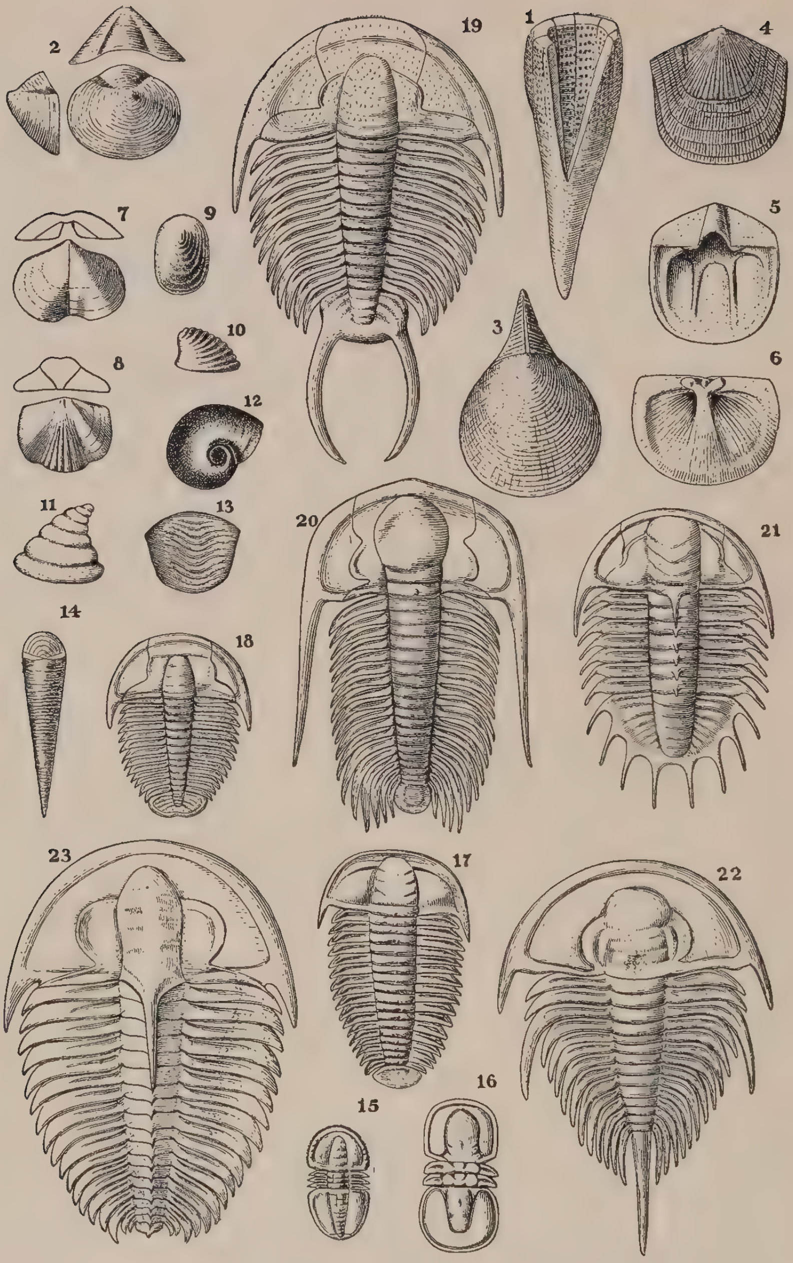


Plate 10. — Cambrian corals (Fig. 1), brachiopods (2–8), gastropods (9–14), and trilobites (15–23).

Fig. 1, *Archæocyathus rensselæricus;* 2, *Paterina bella;* 3, *Lingulepis acuminata;* 4–6, *Billingsella coloradoensis;* 7, 8, *Huenella texana;* 9–11, *Stenotheca rugosa;* 12, 13, *Owenella antiquata;* 14, *Hyolithes primordialis;* 15, *Eodiscus speciosus;* 16, *Agnostus montis;* 17, *Atops trilineatus;* 18, *Ptychoparia kingi;* 19, *Crepicephalus texanus;* 20, *Paradoxides harlani;* 21, *Dorypyge curticei;* 22, *Olenellus thompsoni;* 23, *Holmia bröggeri.*

evidence exists of the presence of land plants, though the lowlands and marshes may have been clothed with feeble vegetation. There is also not a trace of land animals, either of fresh waters or dry lands.

Early Cambrian marine life appears to have been everywhere very much alike, not only throughout America, but in Europe, Asia, and Australia as well; it has therefore been said to be cosmopolitan in character. This feature, however, is probably more apparent than real, and is due to the fact that we as yet know so little of Cambrian life outside of North America. It is very probable that more knowledge will show that there were then as distinct faunal realms as later on. Beginning with the Middle Cambrian, there were clearly two life realms, the greater one of the Pacific (Albertan) and the lesser one of the North Atlantic (Acadian).

Middle Cambrian Burgess Shale Fauna. — In the Selkirk Mountains of British Columbia, famed for scenic grandeur and alpine glaciers, has been found the most interesting locality in the world for Cambrian invertebrates; indeed, it may be said to be one of the most interesting of all time. The bed of Burgess shale that has the fossil community lies on the ridge between Mt. Field and Mt. Wapta, 8000 feet above sea-level. It was discovered in 1910 by Doctor Walcott and he has quarried out of it thousands of specimens described under 70 genera and 130 species. There are seaweeds, sponges, at least one kind of jellyfish, and a remarkable array of annelids preserving the entire body-form, bristles and scales, and commonly also showing the intestinal tract. The most interesting organisms, however, are the crustaceans: shrimp-like forms (branchiopods and phyllocarids), trilobites, and other generalized subclasses suggestive of links between some of the crustacean and arachnidan stocks. In many of these the most delicate limbs are preserved and even parts of the interior anatomy. (See Pl. 11.)

The striking feature of the fauna is that the usual Cambrian forms, especially the brachiopods and gastropods, are rare, while the common fossils are of soft-bodied creatures such as worms, and of crustaceans other than trilobites, stocks seldom seen anywhere by the paleontologist. This wonderful preservation is due to the character of the enclosing sediments, which were very fine-grained soft muds replete with black carbonaceous matter, settled down upon a sea bottom far from land where no currents or waves could disturb them; what is more important, these stagnant black mudholes were lacking in oxygen and reeking with carbonic acid, and therefore almost devoid of decomposing bacteria. On such a death-dealing bottom almost no animal could live. Hence the usual bottom life of the Cambrian is absent, and nearly all the forms are either swimmers or floaters that drifted or swam into the area,

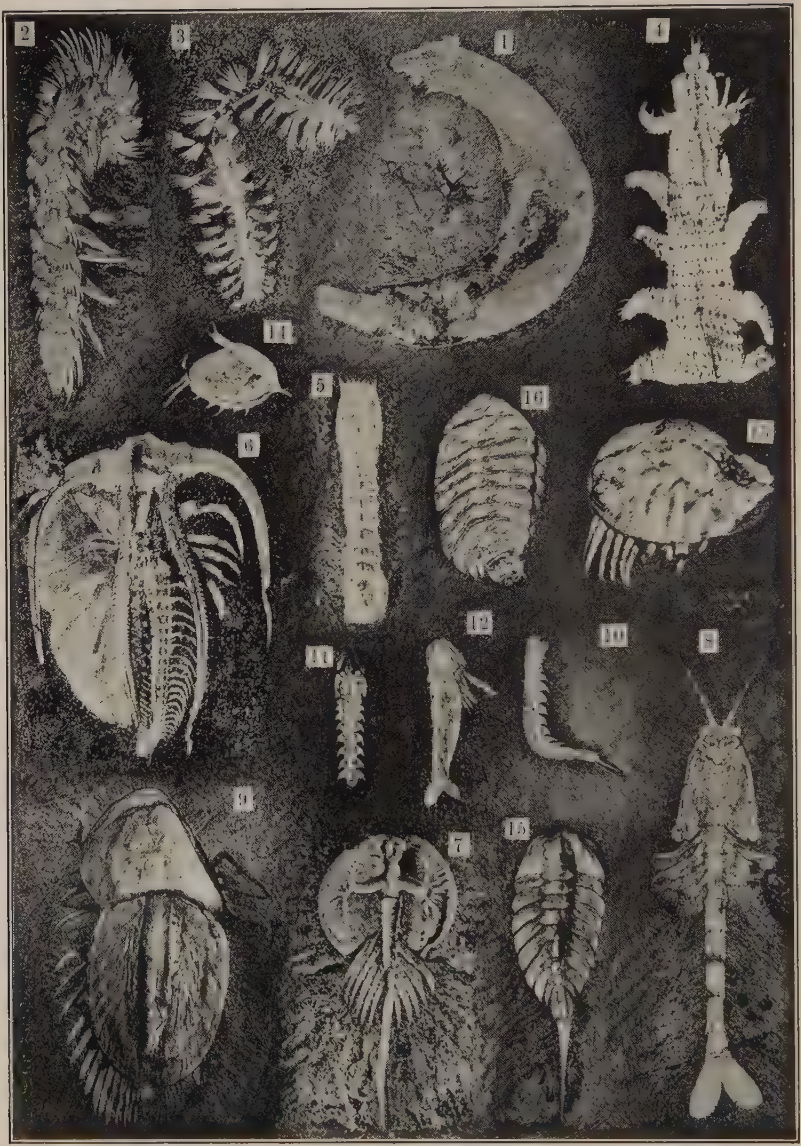


PLATE 11. — Middle Cambrian fossils from the Burgess shale near Field, British Columbia.

Figs. 1–3, annelids (Chætopoda); 4, Onychophora (see Fig. 59A, p. 135); 5–14, Crustacea (5, 6 Trilobita, 7–12 Branchiopoda, 13–14 Phyllocarida); 15, 16, Merostomata.

Fig. 1, *Ottoia prolifica;* 2, *Canadia spinosa;* 3, *C. setigera;* 4, *Aysheaia pedunculata;* 5, *Mollisonia gracilis;* 6, *Marrella splendens;* 7, *Burgessia bella;* 8, *Waptia fieldensis;* 9, *Naraoia compacta;* 10, 11, *Yohoia tenuis;* 12, *Y. plena;* 13, *Hymenocaris ? circularis;* 14, *H. ? parva;* 15, 16, *Molaria spinifera.* All after Walcott (1911–1912).

were overcome by the foul gas and then sank to the bottom, where they were quickly covered by the soft black mud — a pall that is now removed by the pick and hammer of the paleontologist.

Of unique interest in the Burgess shale fauna is the form *Aysheaia pedunculata* (Pl. 11, Fig. 4), described by Walcott as an annelid, but shown by more recent work to be the only known fossil member of the Onychophora, a small group that to a certain extent forms a connecting link between the annelids and the arthropods. Living and fossil forms alike are small animals, not much over 2 inches long. The living ones, best known in the genus *Peripatus*, are land animals breathing air through openings in the skin; the fossil form lived in the sea, and its method of breathing is unknown.

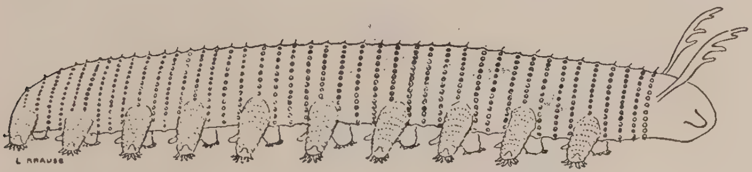


Fig. 59A. — Conjectural restoration of *Aysheaia pedunculata*, a Middle Cambrian onychophorid. After G. E. Hutchinson, 1930.

Life of the Ordovician

The Ordovician seas continued in a broad way the life of the Cambrian, with certain shifts in emphasis in the different areas of deposition, and a certain amount of progressive evolution within the phyla. In the early part of the period, the rocks laid down were so dominantly dolomitic (*i.e.*, altered from limestones, with consequent destruction of most of the contained fossils) that the total number of known species, at least 550, is probably less than a third of those originally present (see Pl. 12).

The most characteristic animals of the St. Lawrencic and Acadic seas in the Early and Middle Ordovician were the *graptolites* (see page 49 and Fig. 60). Many of them were of world-wide distribution, and therefore of much importance throughout the Ordovician and Silurian in determining the age of the strata from place to place.

In the dolomites of the Early Ordovician also occur algæ or seaweeds (*Cryptozoon*), which originally were calcareous and often formed reefs. In favored places are found thick-shelled gastropods and a variety of cephalopods.

During the middle part of the Ordovician, when the seas were very

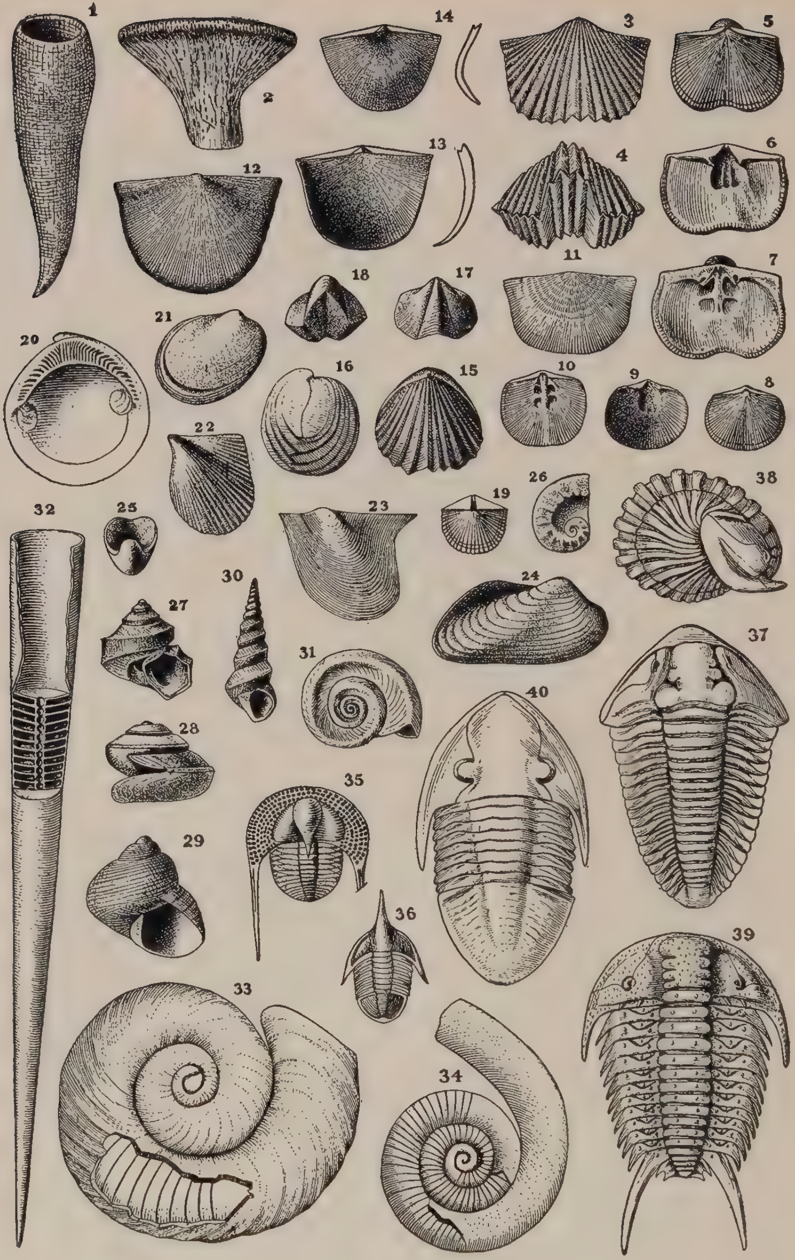


PLATE 12. — Champlainian sponges (Figs. 1, 2), brachiopods (3–19), lamellibranchs (20–24), gastropods (25–31), cephalopods (32–34), and trilobites (35–40).

Fig. 1, *Cyathospongia reticulata;* 2, *Zittelella typicalis;* 3, 4, *Platystrophia laticosta;* 5–7, *Hebertella sinuata;* 8–10, *Dalmanella testudinaria;* 11, *Leptæna rhomboidalis;* 12, 13, *Rafinesquina alternata;* 14, *Strophomena planumbona;* 15, 16, *Rhynchotrema capax;* 17, 18, *Triplecia extans;* 19, *Orthis tricenaria;* 20, *Ctenodonta cingulata;* 21, *Cyrtodonta huronensis;* 22, *Byssonychia radiata;* 23, *Pterinea demissa;* 24, *Colpomya constricta;* 25, *Protowarthia cancellata;* 26, *Cyrtolites ornatus;* 27, *Trochonema umbilicatum;* 28, *Eotomaria supracingulata;* 29, *Cyclonema humerosum;* 30, *Hormotoma gracilis;* 31, *Helicotoma planulatoides;* 32, *Orthoceras multicameratum;* 33, *Plectoceras* (?) *occidentale;* 34, *Schroederoceras eatoni;* 35, *Cryptolithus tesselatus;* 36, *Ampyx nasutus;* 37, 38, *Calymene meeki;* 39, *Ceraurus dentatus;* 40, *Isotelus iowensis.*

widespread, the marine life recorded itself by its fossils more completely than at any other time in the Paleozoic. The waters swarmed with a vast variety of invertebrate animals, and there are known from North America alone more than 2600 species, chiefly of bryozoans (moss animals), brachiopods (see Pl. 12, Figs. 3–19), gastropods (Pl. 12, Figs. 25–31), cephalopods and trilobites (Pl. 12, Figs. 32–40). The first true Paleozoic corals appear here and exhibit a tendency to form small reefs, while the bivalved molluscs and crinids (see page 54) tend to be more common.

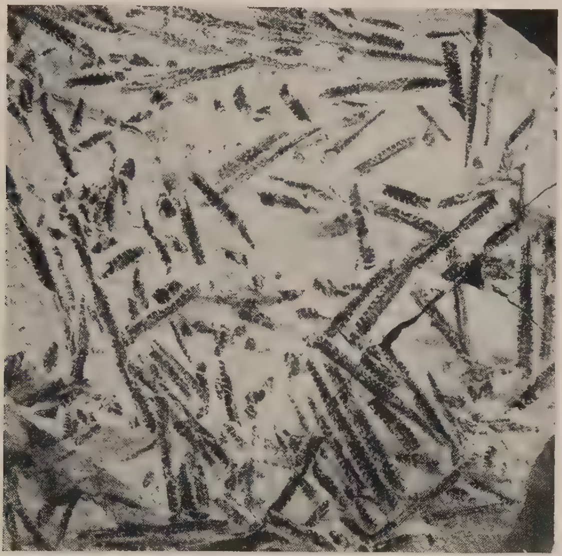


Fig. 60. — The graptolite *Climacograptus typicalis*, from the Ordovician (Eden) of Cincinnati, Ohio. Similar forms are common in the St. Lawrencic geosyncline.

Of greatest interest, however, is an abundance of very fragmentary bones of *fishes* in the Middle Ordovician strata (early Trenton) of Colorado, South Dakota, and Wyoming. These bones represent part of the external armor of fishes several inches in length. They are the oldest fishes known anywhere in the world, and are of the same general nature as the ones that are common in the Devonian. As their remains usually occur in sandstones of near-shore origin, it is thought that they lived in rivers and were washed out to sea, where their armor was broken into bits by the ceaseless waves of the shore.

The Late Ordovician faunas were at first very similar to those of the previous epoch, but the subsequent Arctic and Atlantic invasions introduced new types of animals which gradually changed into others prophetic of Silurian time.

Most predacious and alert of the marine invertebrates of the Ordovician period were the chambered-shelled *cephalopods* (see page 56 and Pl. 12, Figs. 32–34). Most of them had long, straight, cone-shaped shells (orthoceracones), ranging from a few inches in length up to the giant of them all, *Endoceras* (Fig. 61), with a length of 15 feet. Among them also were forms with bent shells, the curvature varying from loosely coiled shells to those tightly wound like a watchspring. All these are nautilids, the most primitive cephalopods, which were masters of the seas in both Ordovician and Silurian times, preying largely on the trilobites.

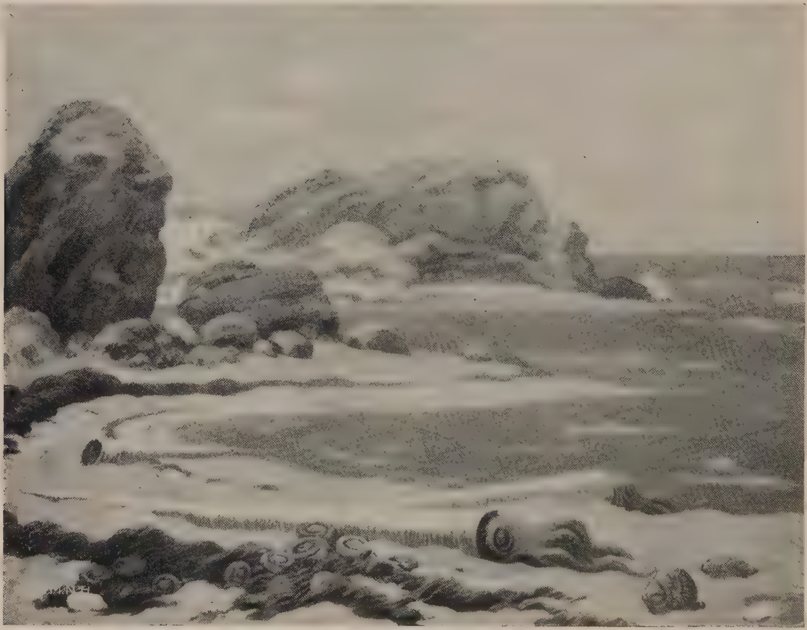


Fig. 61. — A sea beach of the Ordovician period. The largest animal of the time was the straight-shelled cephalopod *Endoceras*, shown in the foreground, which reached a length of 15 feet. Other forms of life were coiled cephalopods, trilobites, and seaweeds. Painted by Charles R. Knight for the Field Museum of Natural History, Chicago.

Of *land plants* of Ordovician time, very little has been recovered (Wales and Kentucky), but enough to show that a feeble vegetation was getting a foothold on the lands.

CHAPTER XII

MIDDLE PALEOZOIC TIME: THE AGE OF FISHES

Middle Paleozoic time is especially interesting because it heralds the rise of the vertebrates and sees the full clothing of the lands with plants, and the appearance of the first land animals. Fishes, we saw in the previous chapter, were present in the Middle Ordovician, and while there is evidence of these animals all through the Silurian it is very scattering and of a fragmented nature until near the close of this period, when it is prophetic of the fullness of fishes in the Devonian, both in the rivers of the lands and in the seas and oceans. Of invertebrates inhabiting the lands, we see in the Silurian the isolated but positive evidence of the earliest air-breathing scorpions; and in the Lower Devonian, of the ancestral spiders, and in the rivers the first bivalve shells. But the most interesting of all this ancient organic evidence is the foot impression of a land-dwelling amphibian found in western Pennsylvania in Late Devonian strata. Accordingly we see thus early in the history of the Earth a balanced world of strange-looking plants and animals, but otherwise not strikingly different from that of our own time.

On the geographic side, we learn of the Caledonian mountains coming up at the close of the Silurian throughout northwestern Europe and Greenland, and furnishing the material for the Old Red sandstone of Devonian age in Scotland and Norway, Spitzbergen, and East Greenland. This marked crustal unrest of the Late Silurian is manifested in America at first only by volcanism, but later, throughout the Devonian, the Maritime Provinces of eastern Canada and the New England States are rising into the Acadian mountains, resulting in a diversified scenery far grander than that of the present.

Silurian Geography

(Plate 13)

North America during the Silurian had about the same general topographic expression as in Ordovician time; that is, the greater interior basin stood but little above sea-level, while the highlands, as heretofore, were toward the margins of the continent. Twice was the interior low area transgressed by great floods, first during the early

Silurian (Alexandrian epoch) and later during the middle part of the period (Niagaran epoch), when from 30 to 40 per cent of the continent was under water. These floods came from the Arctic and down the St. Lawrence, spreading south into the United States, while smaller seas flooded from the Gulf of Mexico northward. There was also a small seaway in the Acadic geosyncline that was especially marked by the life of the English seas. Of the Cordilleric seas little is known.

In Middle and Upper Ordovician times the region from north of Cincinnati to south of Nashville began to rise into a broad low arch, to the east of which was the Ohio basin, and to the west the Indiana basin. This arch, the *Cincinnati axis* or *geanticline*, did not, however, act as a completed separating ridge in the seas until after early Silurian time.

In the Appalachic trough the sedimentaries are coarse-grained throughout until near the close of the period, when much earthy limestone (cement rock) was deposited in very shallow seas, as is indicated by the decidedly sun-dried strata. The coarse-grained rocks are the results of rapid erosion from the highlands of Appalachia and Acadia following the Taconian emergence of Late Ordovician time. The thickest accumulations occur in east-central Pennsylvania.

The island of Anticosti, in the northern part of the St. Lawrencic trough, out where the river widens into the gulf, is one of the " happy hunting grounds " of the paleontologist, because it escaped the folding of the Taconian and Acadian mountain making, and its strata, with their myriads of fossils, lie flat and undisturbed. The Ordovician of the island is 1100 feet thick, and at the top is the very latest Ordovician known in America, the last place on the continent touched by the seas in their retreat. Above, but with the usual break representing an erosion interval, comes 1200 feet of Silurian, representing, however, only the earliest portion; for the higher, younger beds one must go farther south into Gaspé (Port Daniel area). This means that the flat-lying higher Silurian beds were rubbed off in Anticosti, which was toward the north shore of the geosyncline, whereas the Gaspé beds, being in the deeper part of the trough, were preserved in the folded areas. And yet the present distance between the two regions is no more than 70 miles.

To the southwest of Anticosti and Gaspé, but in the Acadic trough instead of the St. Lawrencic one, is another " classic " Silurian section, that at Arisaig, on the north coast of Nova Scotia, with 4000 feet of shales and sandy limestones. Its fossils are particularly significant, since they show that the waters in which they lived had direct connection with those of northwestern Europe, especially Great Britain.

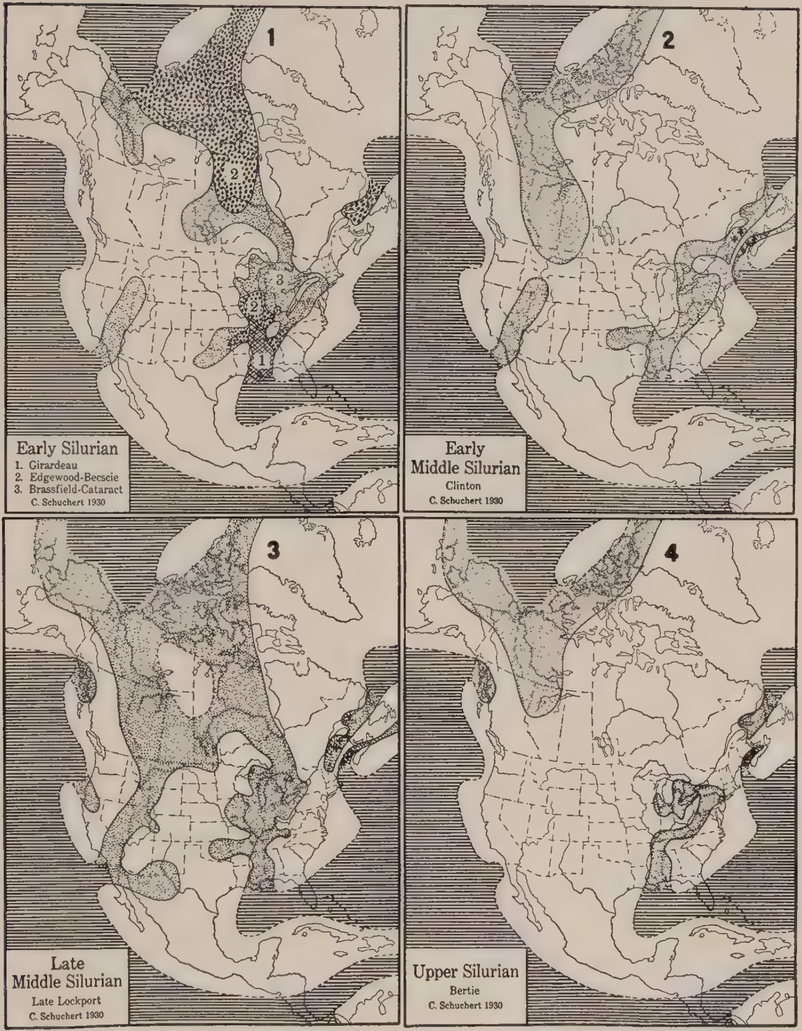


Plate 13. — Paleogeography of Silurian time.

Epeiric seas dotted; oceans ruled. Volcanic regions indicated by crosses.

Map 1 illustrates the progressive spreading of the seas of (1) Girardeau, (2) Becscie, and (3) Brassfield-Cataract times. In Map 3 note the marked Arctic flood. It was in Bertie time (Map 4) that the seas in the United States deposited so much salt and so much of the shallow-water impure limestone that is used in cement making. Map 1 covers the time of deposition of the Silurian marine iron-ores.

Between Buffalo, New York, and the region about Niagara Falls may be studied a typical Silurian section, and one of the finest exposures in America for strata of this time. The gorge between the Falls and Lewiston has the lowest strata reposing on the Ordovician, while the younger deposits appear in sequence toward Buffalo. The diagram on page 143 illustrates the succession of the beds and the picture shows them as they appear in the walls of the gorge of the Niagara River (Figs. 62 and 63).

In the interior part of the continent, the Silurian dolomites and limestones are of clear and warm waters, and most of them were deposited in Middle Silurian time. Coral reefs are common here. (For reefs, see page 177 of Part I.) The strata were widely distributed in two epeiric seas, one being the smaller southern Central Interior sea and the other the far larger one of the Arctic region. Nowhere are these deposits thick.

No mountains were made in North America during Silurian time. Active volcanoes, however, were common in southeastern Maine and western New Brunswick through most of the period, as is indicated by ash beds and lava flows that attain a depth in excess of 10,000 feet. At the same time, other volcanoes were active in northern New Brunswick and in Gaspé, Black Cape in the latter region having over 4000 feet of dark lavas.

In Europe, however, the Silurian was not so uneventful. From southern Great Britain northeast through Scotland, Norway, and Sweden into Spitzbergen there arose at the close of the Silurian the majestic *Caledonian system of mountains*. This was the most intense crustal folding that the region has ever undergone, and the formations were not only folded, but broken on a grand scale and widely overthrust. The Caledonian ranges in their prime must have been grander and loftier than the Alps. In Scotland the folded strata have been shoved to the west in several sheets one superposed over another, and in Norway and Sweden the pre-Devonian strata throughout an area 1100 miles long have been overturned and pushed horizontally eastward many tens of miles.

Economic Products. — In the Middle Silurian Clinton formation of the Appalachic trough from New York to Alabama, there occur in many regions one or more beds, varying from a few inches to 10 and even 40 feet in thickness, of regularly stratified, argillaceous, red iron-ore or hematite (Fe_2O_3). This iron was laid down in a shallow sea. The ores contain from 30 to 50 per cent of iron and were formerly mined throughout the Appalachian Mountains, but are now worked extensively only in the Birmingham region (Red Mountain) of Alabama.

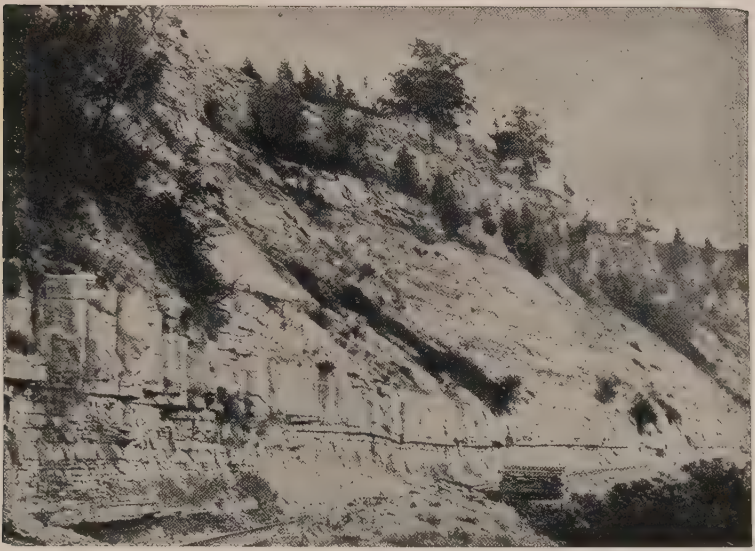


FIG. 62. — General view of New York side of Niagara River gorge. All Silurian. Clinton limestone at track level, Rochester shale in the long slope, Lockport dolomite in the vertical upper walls. Here the Lockport is about 25 feet thick; at the falls it is 80 feet thick; its total thickness is 130 feet.

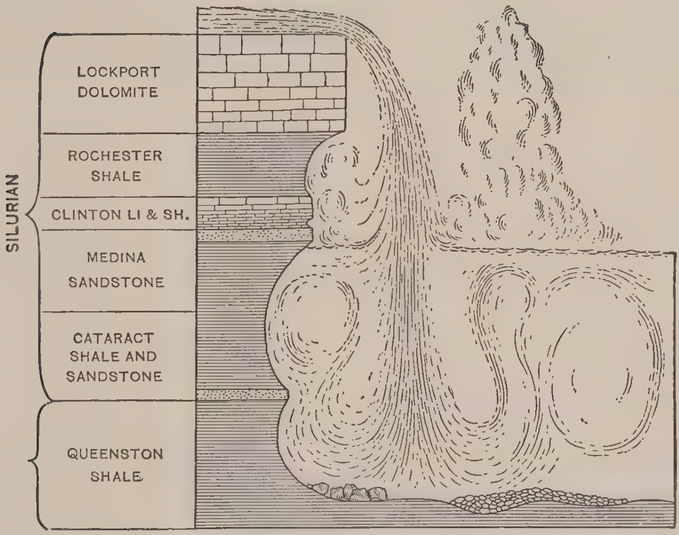


FIG. 63. — Sectional diagram through Horseshoe Falls, Niagara River, showing sequence of formations and depth of water below falls. Height of falls, 158 feet; depth of water, 150–200 feet. Modified from G. K. Gilbert.

It is said that over 600,000,000 tons of these iron-ores are still available under ground.

The Upper Silurian Salina deposits of central New York, southern Michigan, and Ontario are one of the very important sources of salt in the United States. The salt is obtained by deep mining of rock-salt, or by underground solution, the water being forced down through one driven hole and pumped out of another, and the brine evaporated.

Associated with the salt in the red beds of the Salina is considerable gypsum, the ensemble indicating arid or desert conditions. Here is the earliest anticipation of the widespread aridity that was to follow in Devonian time.

DEVONIAN GEOGRAPHY

(Plates 5, 6)

During the Early Devonian, not more than 10 per cent of North America was covered with marine waters (see Pl. 5, Map 1). These seas were long and narrow in the Appalachic, St. Lawrencic, and Cordilleric geosynclines. In the Acadian area their stay was very brief, since this northeastern corner of the continent was elevated and folded in Early Devonian time and again at the close of the period. With the first movement, the more intense of the two, the sea began to retreat throughout the entire area, and the retreat continued until the seaways that formerly connected the Central Interior sea with the St. Lawrencic trough were destroyed forever. This mountain-making movement has been named the *Acadian Disturbance.*

Over the rest of the country, the submergence became markedly general late in the Early Devonian and attained its maximum in late Middle to early Upper Devonian time, when at least 38 per cent of the continent was covered by sea (Pl. 6, Map 5). The waters were warm, for they brought from the Gulf of Mexico and up the St. Lawrence many coral species which built extensive reefs. Later there was also an arctic invasion through the Cordilleric sea, and it likewise brought an abundance of corals, this being particularly true for Alaska and the Mackenzie Valley.

The longest sequence and the thickest series of Devonian deposits occur in the northern Appalachians, where most of the materials are shales and fine-grained sandstones. Pennsylvania was the central area of a great delta formed at the mouth of the large rivers that flowed out of the highlands to the east and northeast, in which latter region there was mountain making and volcanic activity throughout much of the time of the delta accumulation. The greatest thickness is where the Susquehanna River has cut through the mountains; here a maximum depth of nearly 13,000 feet of Devonian shales and sandstones occurs, becoming increasingly coarser, less marine, and more rapid in accumulation with the progress of time, that is, toward the top. Along with the greater rapidity of accumulation the marine faunas become increasingly scarcer upward in the section, and the sediments change in character to red beds, most of which are of fresh-water origin, marked by ripples, mud-cracks, and rain prints, and having land plants and fresh-water fishes. (See Pl. 6, Maps 5 and 6.)

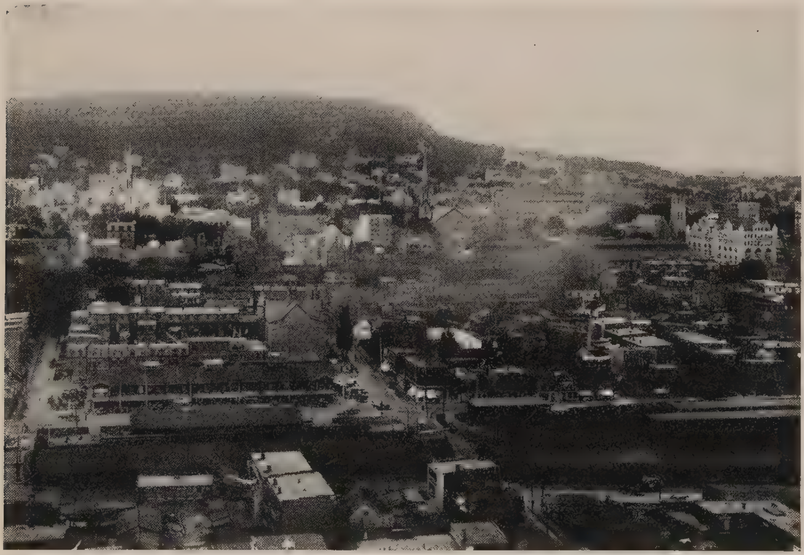


Fig. 64. — Mount Royal, overlooking the city of Montreal, with McGill University at its base. A volcanic neck, intruded into Ordovician strata in Devonian time. Photograph by Notman.

Also belonging to this great delta are the thick sediments now seen in the Catskill Mountains, on the west side of the Hudson River, the most imposing single Devonian pile in the United States. Here, however, the beds are not folded as they are in Pennsylvania. From this central and rapidly subsiding delta, the deposits thin rapidly to the north, west, and south.

Another big Devonian delta was present in Gaspé, into which were carried some of the detritals brought down by rivers that had been rejuvenated by the Acadian Disturbance (see Pl. 6, Map 5).

During the Upper Devonian the seas were gradually withdrawn, earliest in the southern Mississippi valley, then over most of the interior of the continent, still later in the Cordilleran area, and lastly in the southern Appalachic trough (see Pl. 6, Map 6).

The volcanic activity seen in the Acadian region in Silurian time became even more marked there throughout the Devonian, and especially in the latter part of the period, occasioned, no doubt, by the rising of the Acadian mountains. The cones of the volcanoes are now eroded away, leaving exposed the harder volcanic necks which were intruded into the Ordovician strata. One of these resurrected volcanoes is Mount Royal (Fig. 64), back of McGill University in Montreal, and others are the Monteregian Hills farther east. There are eight of them in all, each covering from one-half to 30 square miles, and they rise abruptly from 600 to 1275 feet above the St. Lawrence plain. Finally, toward the end of the period the rising land was intruded by great deep-seated masses of flowing granite. Some of the crystalline rocks of the White Mountains of New Hampshire and others of Vermont, Maine, New Brunswick, and southern Quebec are intrusives that accompanied the making of the Acadian mountains.

The northern half of the British Isles was also the theater of igneous activity on a large scale in Devonian time, as was the region around the Christiania fiord in southern Norway.

Devonian Fresh-water Deposits. — In the Devonian, fresh-water deposits for the first time take on interest. Such were, of course, present in the earlier eras, but there was no land life present to be preserved in them, and they were mere rock records. With the Devonian, however, there were plants and animals on hand to be buried in the fresh-water deposits and thus endow them with added significance. From this time onward, the geologic record often bears testimony to the continental origin of certain deposits and their entombed life.

The oldest known of these fresh-water deposits with an abundance of fossils are the Old Red sandstones of Scotland, a tremendously thick series of coarse detritals and volcanic effusives, seemingly accumulated under a dry climate in valleys between high mountains that were upheaved during the Caledonian Disturbance. Their maximum thickness may be as great as 37,000 feet, though in no single area is there more than 20,000 feet. These deposits are often very decidedly cross-bedded, and the materials are usually poorly assorted. The conglomerates are frequently of great thickness, with broken blocks as large as 8 feet in diameter. Ripple-marking is frequent, and the mud-cracking is deep, indicating that there was long exposure to dry air. There are also rain-drop impressions. All of these are characteristic of continental deposits. While the rocks are not red throughout the series, this is nevertheless the dominant color; it is usually due to the quartz grains being coated and held together by a crust of earthy iron oxide. Some of the red sandstones of Scotland are locally full of wind-worn sand grains, and are highly false-bedded in places, like sand dunes.

Color played an important part in the study of rocks and their interpretation by the pioneer geologists. In Britain, for example, where Stratigraphy was largely developed, the best and earliest known formations were the " black " rocks which furnished coal (Carboniferous), and the much higher and younger " white " ones, or Chalk, which yielded lime for the tilled fields (Cretaceous). These two series were readily distinguishable, but the " red " rocks offered something more of a problem in that they lay both above and below the coals! The difficulty was surmounted by calling those above the Coal Measures the " New Red " (Triassic), while those below received the name of " Old Red " (Devonian).

These Old Red rocks, with their great thicknesses and their wealth of strange fishes (to be described later) were so conspicuous as to attract much attention. They were the favorite topic of a young quarryman of Edinburgh, Hugh Miller by name, whose later career took him to the editorship of a newspaper called the *Witness*, a lusty organ of the Free Kirk; and the sketches he wrote therein about these red rocks were later assembled into a book called " The Old Red Sandstone," which, first appearing in 1841, by 1872 had gone into sixteen editions and can still be read with delight.

In America there are no Devonian strata that were accumulated in inland mountainous areas, like those of Scotland, Spitzbergen (here 10,000 feet thick), and East Greenland. The American deposits are, rather, those of deltas formed by large rivers flowing into the sea, apparently also under a rather dry climate. Certain of the Upper Devonian formations of New York (Oneonta and Catskill) and the sandstones of Gaspé are held to have been laid down in great coastal lagoons receiving terrigenous sediment rapidly and in vast quantity from a rapidly rising highland. It is in these regions that are found the American Old Red fishes, which appear to have come from the rivers and not from the sea.

Life of the Silurian

Land plants are not surely known as fossils back of the Middle Silurian, although earlier softer ones may have merely failed of preservation; that such must have been present in the Middle Ordovician is proved by the abundance of little fishes then living in the rivers of Colorado and

Wyoming, which must have had plants to feed upon. In the Early Devonian, however, land plants were common and the best known forms, *Rhynia* and *Hornea* (Fig. 65), have about the same organization as the living mosses, that is, are nothing more than rootless and leafless, branching and duct-bearing stems not over 8 inches tall, covered with scattering breathing pores and specialized tips in which the reproductive spores are developed. These oldest known land plants are therefore more primitive in organization than ferns or rushes, but are structurally far higher than seaweeds in having air-breathing pores.

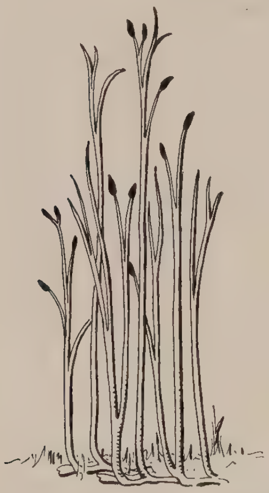


FIG. 65. — One of the oldest known land plants, *Rhynia*, found in the Lower Devonian of Scotland. These were merely branching stems, topped with spore cases, devoid of roots and leaves, and not over 8 inches tall. After Kidston and Lang, from Schuchert and LeVene's *The Earth and its Rhythms* (Appleton).

The most notable advance in Silurian life was the *first appearance of air-breathing land animals.* These were true scorpions and in general structure very much like those living to-day (see Fig. 66, 4, 5). Other air-breathing animals were the thousand-legs (myriapods) found in the late Silurian of Wales in association with eurypterids. Land plants were now more common, and there was a considerable variety of fresh-water fishes. From this time onward, in fact, we shall see wider and wider home-making on the dry lands by the emerging life of the rivers.

In certain isolated localities, where the waters were brackish and but little other life apparently existed, lived characteristic Silurian water-breathing animals called "sea scorpions" or *eurypterids* (Fig. 66, 1–3); they were not scorpions (*i.e.*, air-breathers), though they were much like the latter and may have been ancestral thereto. The largest American species (*Pterygotus buffaloensis*) is found in New York State, where it reached a length of nearly 9 feet.

In the seas, the invertebrates were still dominant (see Pl. 14). Upward of 2500 species have been described from the American Silurian, the common ones being mainly corals, crinids (see page 54), bryozoans, brachiopods, and trilobites. True graptolites were still common in the European seas, but in America they are not often found.

Of trilobites there were still many species, some of which were bizarre looking animals with spines on the head and tail (see Pl. 14, Figs. 18–21).

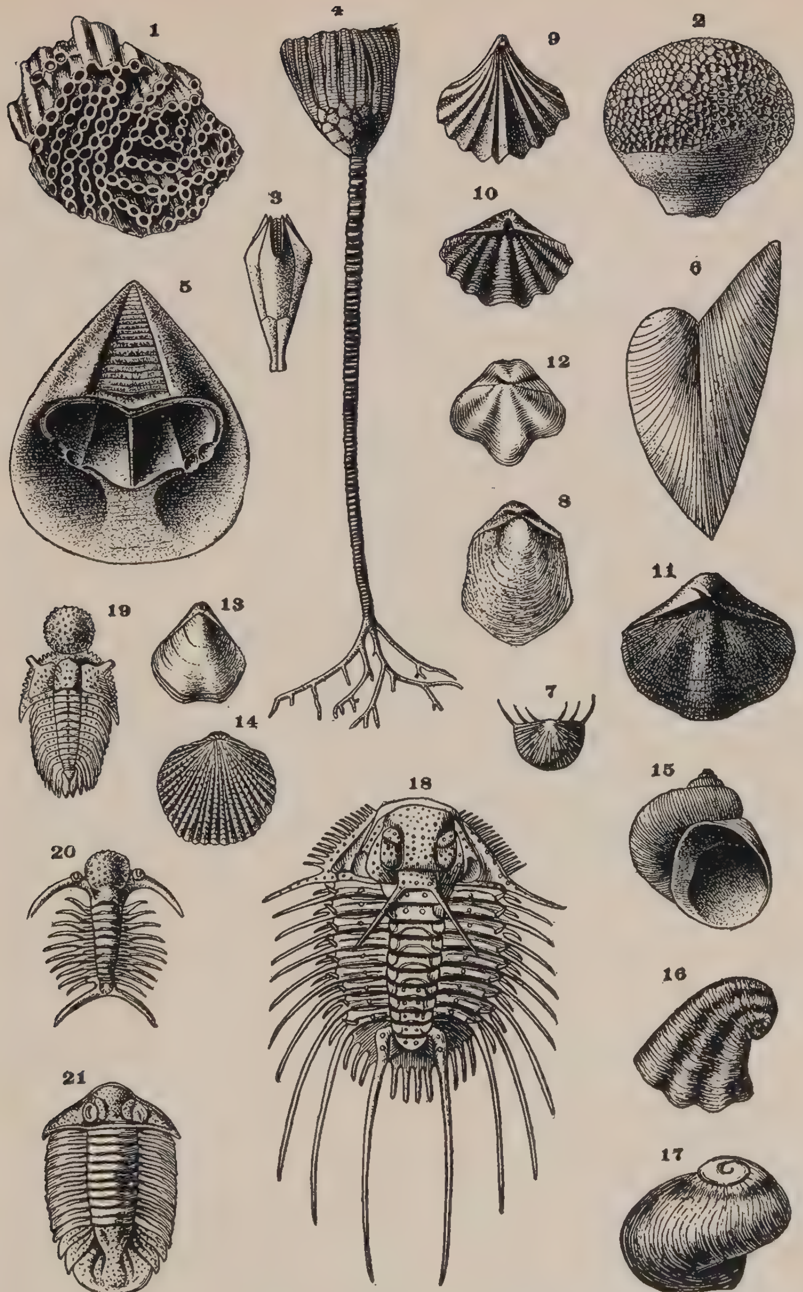


PLATE 14. — Silurian corals (1, chain coral; 2, honeycomb coral), blastid (3), crinid (4), brachiopods (5–14), gastropods (15–17), and trilobites (18–21).

Fig. 1, *Halysites catenulatus;* 2, *Favosites occidentalis,* × $\frac{3}{4}$; 3, *Troostocrinus reinwardti;* 4, *Eucalyptocrinus crassus,* × $\frac{1}{2}$; 5, 6, *Monomerella noveboracum,* × $\frac{1}{2}$; 7, *Chonetes cornutus;* 8, *Pentamerus oblongus,* × $\frac{1}{3}$; 9, *Rhynchotreta americana;* 10, *Spirifer crispus;* 11, *S. radiatus,* × $\frac{2}{3}$; 12, *Hyattidina congesta;* 13, *Whitfieldella nitida,* × $\frac{1}{2}$; 14, *Atrypa nodostriata;* 15, *Strophostylus cyclostomus,* × $\frac{2}{3}$; 16, *Platyceras angulatum;* 17, *Diaphorostoma niagarense,* × $\frac{1}{2}$; 18, *Ceratocephala dufrenoyi;* 19, *Staurocephalus murchisoni;* 20, *Deiphon forbesi;* 21, *Metopolichas breviceps,* × $\frac{1}{2}$.

Mainly after the New York and Indiana State Surveys. Also from Scott and Zittel.

Life of Devonian Time

There is no more significant or picturesque period in the history of the Earth than the Devonian. This is the time when the former nakedness of the lands becomes clothed with a deeper verdure and the first forests appear, providing the needed homes and food for the invasion of the continents by the ever-hungry denizens of the rivers and seas. This invasion of the land is fairly under way in the Devonian, chiefly in the rivers and lakes, but due to the widespread arid climates a fierce struggle is instituted among the inhabitants of the then temporary waters, resulting in the dominancy of the better equipped air-breathing fishes, an issue prophetic of vertebrate ascendency upon the lands, hereafter never to be questioned in its onward sweep to its culmination in man.

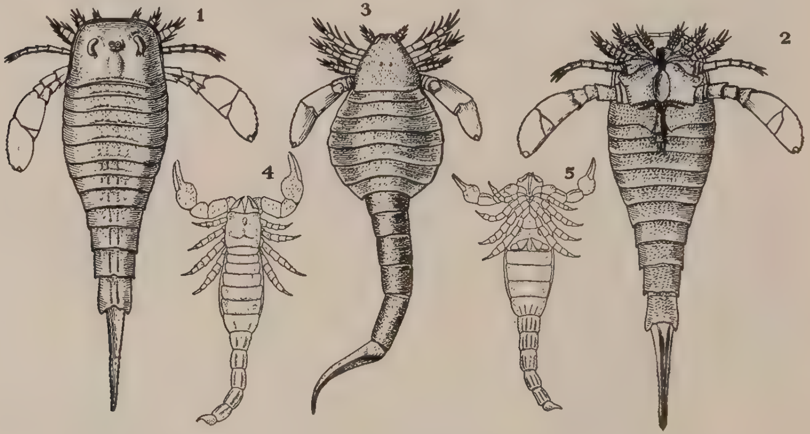


Fig. 66. — "Sea scorpions" or eurypterids (1–3) and scorpions. 1, 2, *Eurypterus remipes;* 3, *Eusarcus scorpionis;* 4, *Palæophonus nuncius;* 5, *P. hunteri.*

The seas of Devonian time swarmed with corals and shellfish, and in general the life was not very unlike that of the Silurian. The corals were widespread, ranging from Alaska south to Louisville, Kentucky, which has a famous reef making the Falls of the Ohio. Of echinoderms, the blastids (Pl. 15, Figs. 3, 4) were common, and may have originated in America. Trilobites were still abundant, but greatly reduced in variety (see Pl. 15, Figs. 21–24).

Especially characteristic of Devonian marine realms were the *brachiopods* (Pl. 15, Figs. 5–12). They were then in their heyday, no fewer than 700 kinds being known from this continent alone. The commonness of these shells in Devonian rocks has led to various speculations as to their numbers. James Hall, state geologist of New York from 1837 to 1898, and one of the most picturesque figures in American geology, relates that children " dry dredging " for him in the Lower Devonian fields of Albany County collected in a period of 14 years about 60,000 free specimens, which represent only the comparatively small number that weathered out of the rocks. The strata from which these fossils came are about 10 feet thick, and the area collected over was about one-seventh of a square mile; it is safe to say that within this very limited area the limestones in question have many millions of brachiopods. Another lifelong student of Devonian rocks, Hall's successor, John M. Clarke, estimates that the famous Percé rock off Gaspé contains, within its length of 1400 feet and its height of 250 feet, 600 million specimens of three brachiopod species alone!

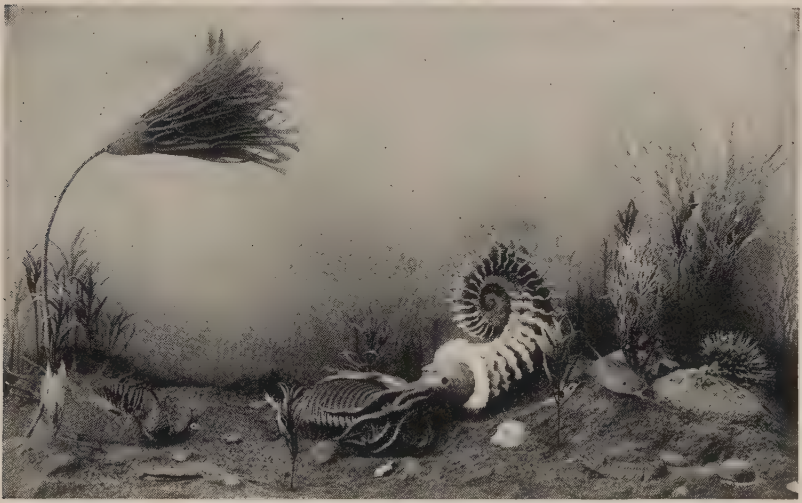


Fig. 67. — Sea life of Devonian time. The plant-like animal at the left is *Scytalocrinus*, a crinid; in the center is the cephalopod *Gyroceras*, attacking *Homalonotus*, a trilobite; at the right are other trilobites, and seaweeds. Restoration in the New York State Museum at Albany.

With the Devonian, the marine fishes first came into prominence, and their rise was accompanied by the decline of the trilobites, upon which they probably fed. The most striking fishes were the highly armored types (Arthrodira, Pl. 16, Fig. 4).

The fresh waters in Devonian time must for the first time have abounded in life, an inference justified by the fact that over one hundred species of fishes alone, in more than forty genera, are known in the

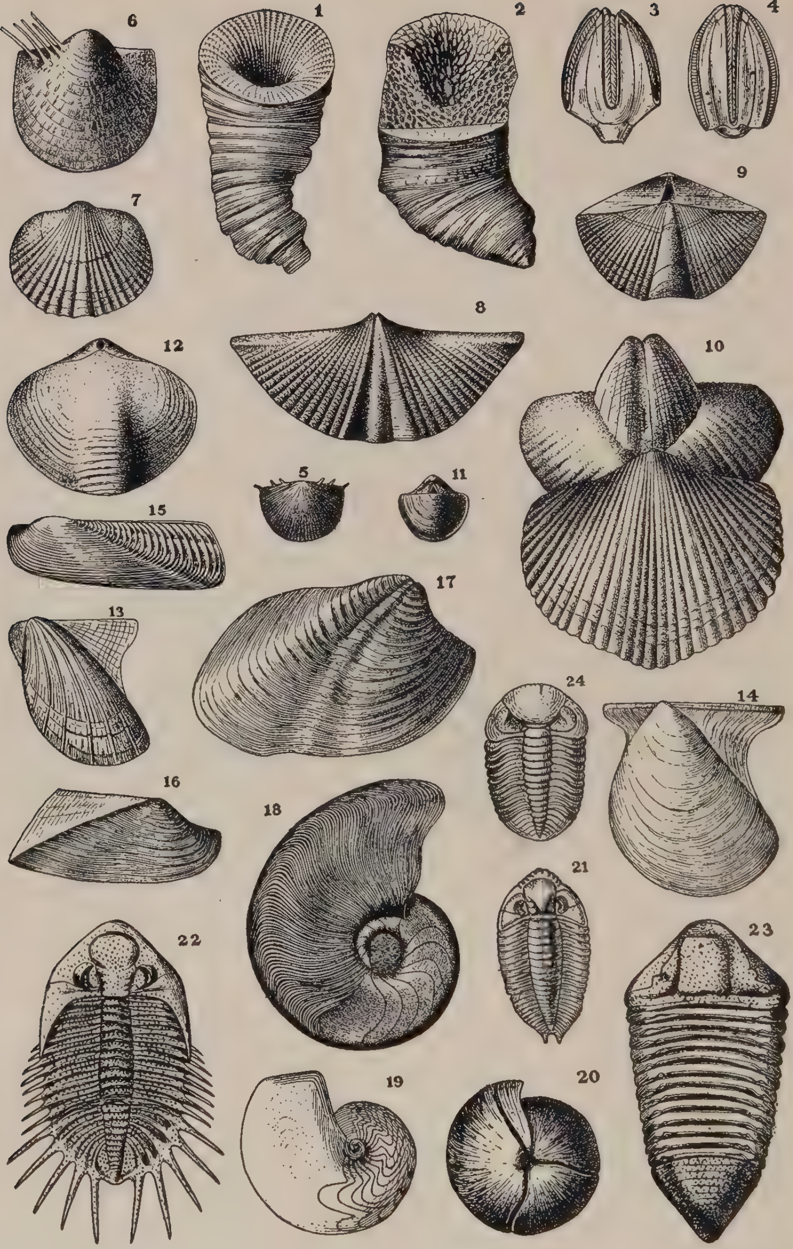


Plate 15. — Devonian corals (1, 2), blastids (3, 4), brachiopods (5–12), lamellibranchs (13–17), cephalopods (18–20), and trilobites (21–24).

Fig. 1, *Heliophyllum halli;* 2, *Cystiphyllum vesiculosum;* 3, *Pentremitidea filosa;* 4, *Granatocrinus leda;* 5, *Chonetes setigerus;* 6, *Productella hirsuta;* 7, *Tropidoleptus carinatus;* 8, *Spirifer pennatus* (*mucronatus*); 9, *S. medialis;* 10, *S. arenosus;* 11, *Ambocœlia umbonata;* 12, *Athyris spiriferoides;* 13, *Pterinea flabellum;* 14, *Actinodesma erectum;* 15, *Orthonota undulata;* 16, *Goniophora carinata;* 17, *Grammysia bisulcata;* 18, *Aphyllites vanuxemi;* 19, *Manticoceras oxy;* 20, *Brancoceras sulcatum;* 21, *Odontocephalus selenurus;* 22, *Cryphæus punctatus;* 23, *Dipleura dekayi;* 24, *Phacops bufo.*

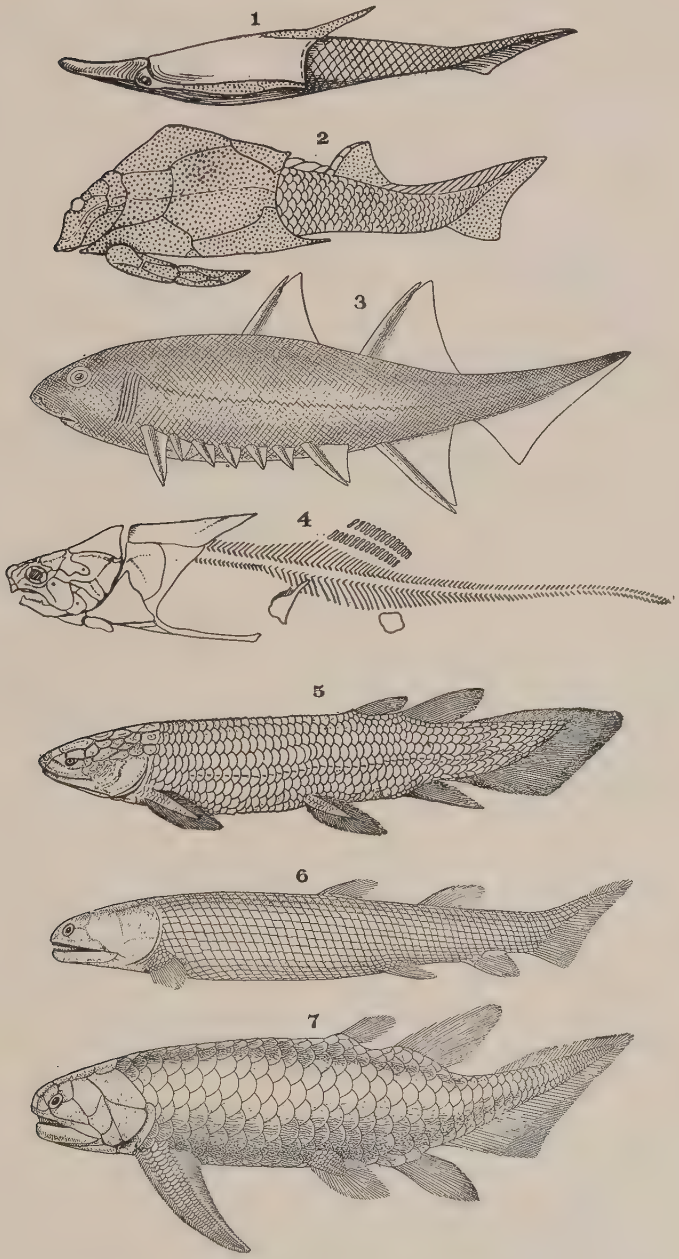


Plate 16. — Devonian marine and Old Red sandstone fishes.

Primitive armored fishes or ostracoderms (1, 2), primitive fresh-water shark or acanthodian (3), "terrible fish" or marine arthrodire (4), lungfish (5), and ganoids (6, 7).

Fig. 1, *Pteraspis rostrata;* 2, *Pterichthys milleri;* 3, *Climatius macnicoli;* 4, *Coccosteus decipiens;* 5, *Dipterus valenciennesi;* 6, *Osteolepis macrolepidotus;* 7, *Holoptychius flemingi.*

continental deposits of this time. The oldest forms were small spinous sharks known as acanthodians (see Pl. 16, Fig. 3). Various kinds of ganoids (Pl. 16, Figs. 6, 7), fishes related to the living sturgeons and gar-pike, were the common fresh-water types, and there were also many lung-fishes or dipnoans (Pl. 16, Fig. 5). The group which has probably aroused more speculation than any other is that of the curious aberrant "winged" fishes known as Ostracodermi, which lived in the rivers (Pl. 16, Figs. 1, 2).

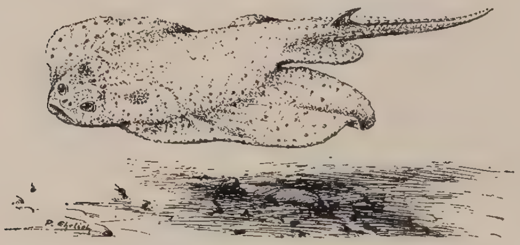


Fig. 68. — Restoration of a highly specialized marine fish, *Gemündina stürtzi*, from the Lower Devonian (Hunsrück slate) of Germany. Length, about 10 inches. From Broili.

These Devonian fishes were a strange lot (see Fig. 69). The Old Red was long considered to be unfossiliferous, and it was Hugh Miller who first proved it to be a veritable storehouse of fish remains; in fact, he called the Orkney Islands a "land of fish," geologically speaking, and the same might be said of the "Hugh Miller cliffs" of the Gaspé. The most striking characteristic of these ostracoderms that Miller found and described in his popular books was their armor; as Clarke says, they "marched down his pages like medieval warriors full panoplied and shining in their coats of mail." Conspicuous among the curious horde were the "winged" *Pterichthys* (Pl. 16, Fig. 2), with a head "as entirely lost in the trunk as that of the ray or the sunfish," a back running up to a hump and covered with bony plates, two paddles set on at the "shoulder," and a long angular tail; and *Cephalaspis* (Fig. 69), that smaller armored fish, with a trilobite-like head, of which the Rev. Dr. Buckland, pioneer British geologist, said: "What an appropriate ornament, if set in gold, for a lady geologist!"

The American Devonian seas were dominated by the arthrodires, so called from the sliding joint that allowed the head to move up and down — a rare feature among fishes. Of these, *Dinichthys*, the "terrible fish," is known in more than forty species, one of which reached a length of 20 feet.

Less bizarre than these aberrant armored types, but of greater evolutionary import, were the Devonian lung-fishes, of which more will be said in a later chapter.

Of vertebrates higher than the fishes, the only evidence rests upon one foot imprint (*Thinopus*), nearly 4 inches long, which was found near the top of the Upper Devonian of western Pennsylvania (Fig. 70). This indicates the presence of a salamander-like animal with a probable length of nearly 3 feet.

Plants and the Climate. — In the Devonian there is much evidence of land plants, but it is not until the Middle Devonian that we can speak of assemblages of plants, or floras, for in the early part of the period these fossils are still very scarce. In the later part of Devonian time there was a considerably diversified flora, forming the oldest or first forest, in which flourished fernlike plants, fernlike trees (*Psaronius*), rushes, tall ground pines (lycopods), and primitive evergreens with woody trunks nearly 2 feet in diameter. Drifted logs of these very ancient trees are often found in the marine deposits of Upper Devonian time. At Gilboa in the Schoharie Valley, New York, have been found a large number of great stumps and spreading roots of tall trees still standing in their native soil (see Fig. 71). These trees attained a height of 30 to 40 feet, and are thought to have been seed-ferns.

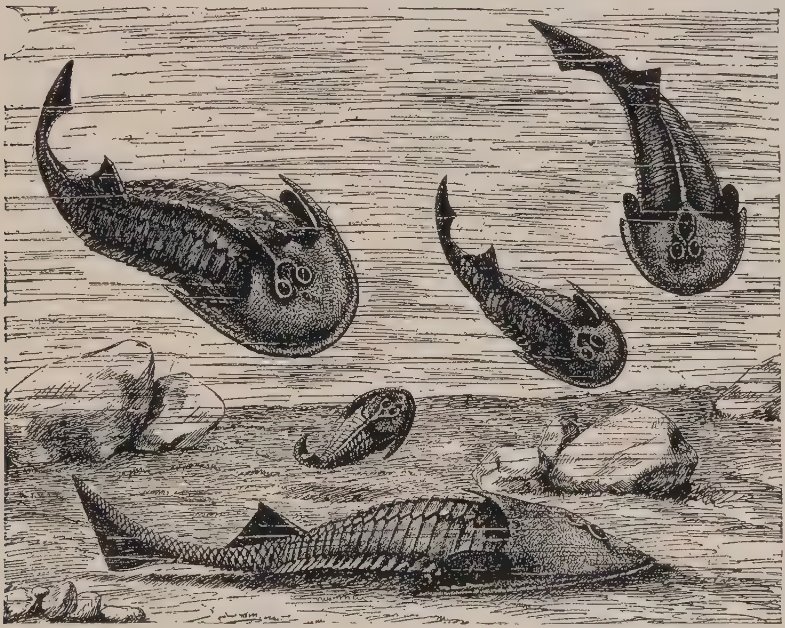


FIG. 69. — Small armored fishes (ostracoderms), restored (*Cephalaspis*). Lower Devonian of Europe. After Koken, from Museum Guide of University of Tübingen.

One of the most remarkable facts in connection with this flora was its wide distribution and uniform character throughout eastern North America and into the Arctic region, Spitzbergen, and northwestern Europe, indicating equable climates and the complete union of North America and Europe across southern Greenland, Norway, and Great Britain. None of the trees show annual rings of growth, and it is held that the general climate of this time was uniformly warm though semiarid, the known forests being localized in wet places along the valleys and in the swamp areas near the sea front. That the climate was warm is further shown in the wide distribution of the reef corals of the seas, which extended even into arctic regions, but that the conditions were more or less semiarid in eastern North America and western Europe is suggested further by the prevalence of oxidized and red continental deposits.

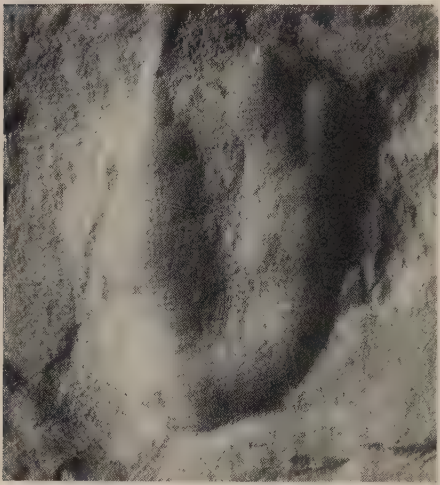


FIG. 70 — Cast of the oldest known amphibian footprint (*Thinopus antiquus*), from the Upper Devonian of Pennsylvania. About 1/2 natural size. Peabody Museum, Yale University.

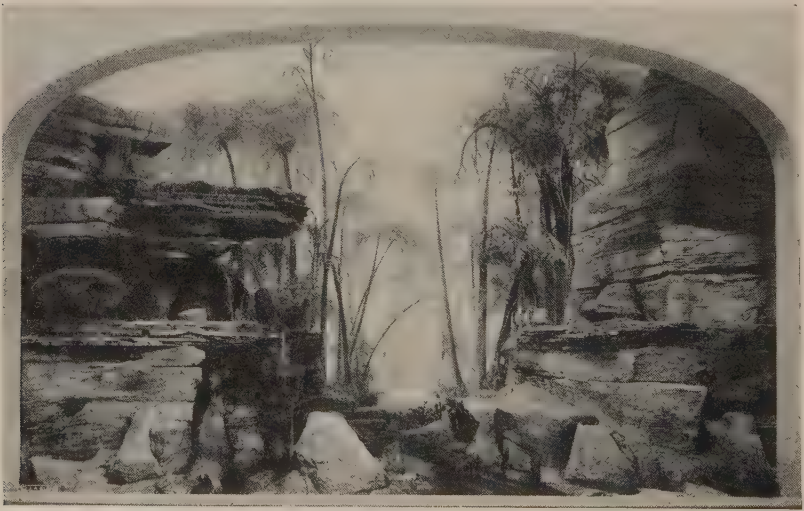


FIG. 71. — The Devonian forest at Gilboa, New York, as restored in the New York State Museum at Albany. The remains of this old forest were discovered during construction work for the Catskill reservoir. The trees are the oldest known seed-ferns (*Eospermatopteris*).

CHAPTER XIII

LATE PALEOZOIC TIME: THE AGE OF AMPHIBIANS AND COAL-MAKING PLANTS

The highly varied Upper Paleozoic rocks were originally regarded as comprising but a single period of time, and because coal (carbon) is common in them, they were called the Carboniferous System. In western Europe, where Geology had its inception, the coal-bearing strata are of wide occurrence, and in England the miners have long used the term " Coal Measures." At present the Europeans recognize two systems, Carboniferous (Lower and Upper) and Permian, while in America three are now in wide use, namely, Mississippian, Pennsylvanian, and Permian.

The formations of the Late Paleozoic are of extraordinarily wide distribution at the surface in the United States, because east of the Great Plains no later deposits covered them except the thin Pleistocene drift of the northern states. The strata of the Pennsylvanian system have much coal near the surface, where it is easily mined; and as coal is the consolidated residue of plant accumulations, it follows that these strata must be also rich in the flora of this period, and so they are. As a result, the trees and plants of Pennsylvanian time are probably better known than those of any subsequent period, though less well understood than the later ones because they differ so greatly from modern plants.

Due to the great abundance and many different kinds of plants living in the genial and moist climates of the Pennsylvanian, there was a varied assortment of foods, and this proved a great stimulus to the animals. Hence the time had many kinds of primitive insects, spiders, scorpions, and thousand-legs, along with a few land snails. The single amphibian footprint in the Late Devonian is supplemented by many more in the Early Carboniferous, but no bones or skeletons are known in America until Middle Pennsylvanian time. Late in that period the atmosphere became drier, mountains rose in many parts of the world, and in consequence there was then an increasing variety of climates, from moist warm ones in the low lands in lower latitudes to cool and desert ones on the plateaus and in the mountains of the several continents. Consequently the amphibian world of the Late Pennsylvanian became more active and alert and put on a covering of scales, and so gave rise to the reptilian world of the Early Permian. In the next chapter we shall trace this evolution further.

Mississippian Geography

(Plate 17)

The Mississippian of North America is marked by two floods. The first of these (Waverlian) covered 26 per cent of the continent, and the second (Tennesseian) less than half that extent. The geologic record in general is decidedly different from that of the succeeding Pennsylvanian, for the Mississippian is chiefly of the sea, while the later period in the eastern half of the continent shows an alternation of the sediments of marine floodings with accumulations of coal beds in vast more or less fresh-water swamps. In other words, the Mississippian is a recurrence of Devonian conditions, while the Pennsylvanian alternates between sea and land.

The most striking change in the geography of the Mississippian is the reappearance of the Cordilleric sea to the east of the borderland Cascadia, spreading far and wide in the Rocky Mountains region the *Madison limestone* (Pl. 17, Map 1). No other sea in the West left as imposing a limestone record. The formation is exceedingly massive, and streams in many places have cut deep and picturesque canyons through it. Of the same time is the Redwall limestone that forms the most brilliant cliffs in the walls of the Grand Canyon; the red color, however, is due to the wash from the Supai formation above. The record of this wide sea is known also in Alberta and in the Mackenzie River region, and it extended into the Arctic as well. At times it connected with the seaways of the Mississippi basin, which, with clear waters, were likewise depositing limestones and oölites.

In the Mississippi Valley, the deposits of the Early Carboniferous seas succeed those of the Devonian ones conformably, and the boundary lines can be determined only by the aid of the faunas. To make matters still more difficult, the Devonian often terminates with a black shale series, as in Kentucky, Indiana, and Ohio, and the Mississippian as often begins with a similar one, both due probably to cul-de-sac seas.

Eastern North America had the borderlands of Appalachia and Acadia as before, and it was these highlands that were furnishing débris to be laid down as muds and sandstones in the shallow seaways in Acadia and in the United States to the west of Appalachia.

Toward the close of the Mississippian, the unstable Acadian area was again in turmoil, folding the Mississippian rocks of Nova Scotia and New Brunswick (Horton, Cheverie, Windsor, and older formations)

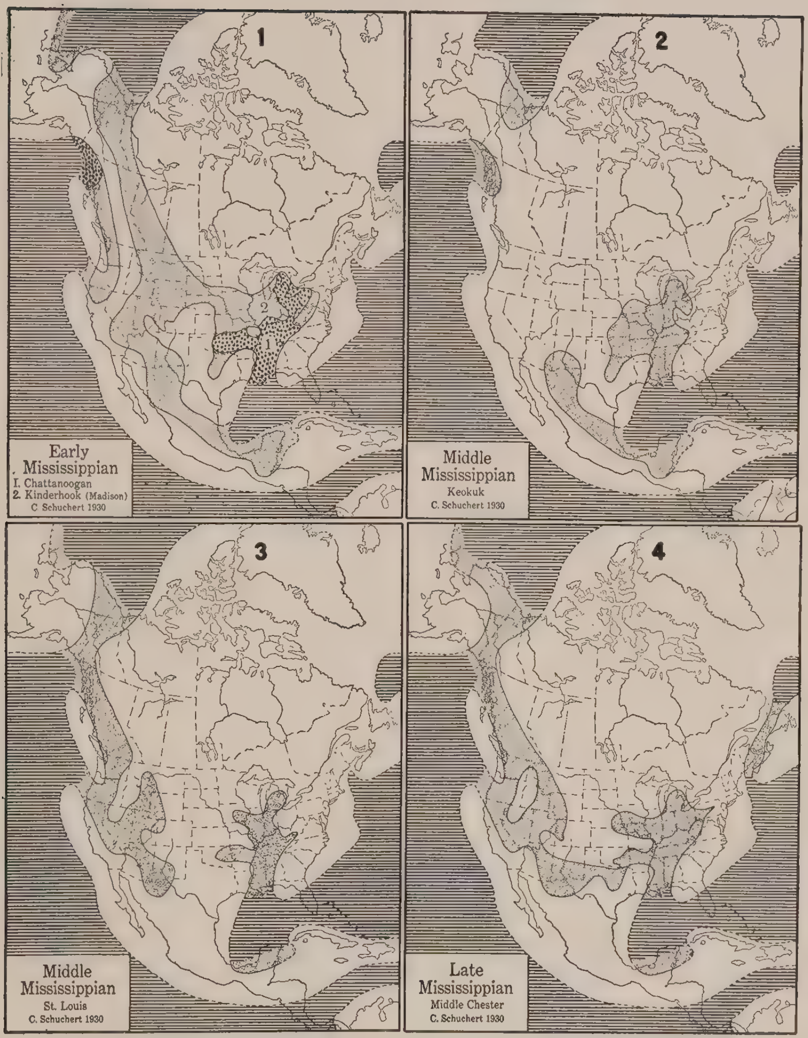


Plate 17. — Paleogeography of Mississippian time.
Epeiric seas dotted; oceans ruled.
Note the two times of extensive flooding in Maps 1 and 4.

into a series of mountains (Windsor Disturbance). That there was also crustal movement at this time in the southern Appalachian region is indicated by at least 10,000 feet of coarse deposits (conglomerates, sandstones) of Early Pennsylvanian age in central Alabama (Cahaba coal field), which must have come from a newly risen highland to the east. The same was true for the old lands of Siouia and Llanoria, which were furnishing thousands of feet of Early Pennsylvanian detritals to the seas of Colorado, Utah, New Mexico, and west Texas. As a result of such extensive crustal movement, the emergence of the continent seems to have been complete at the close of Mississippian time.

Mountains were also made at this time in Great Britain and Germany.

Pennsylvanian Geography

(Plate 18)

The outstanding features of the Pennsylvanian period are its variable geography, resulting in great coal-making swamps, and its abundance of coal-making plants. The period was especially one of crustal unrest. Previously during the Paleozoic the times of mountain making occurred toward the close of the periods, but during the Pennsylvanian the mountains were raised repeatedly. The seas, due to this marked instability of the Earth's surface, oscillated back and forth over the low lands more actively than before. The climate was warm and genial the world over, and the lands bordering the epeiric seas were moist, with an abundant and well distributed rainfall. Under these conditions great fresh-water swamp areas developed in the lowlands, in which was accumulated, through plant decay, the greatest of the world's coal reserves.

Until 1891 all of the strata of the Pennsylvanian period were known as Coal Measures, but as geologists must have an accepted area for comparison, H. S. Williams proposed that this standard for correlation be the state of Pennsylvania, where coal has been mined for a century and where the coal floras are well known; and the period was accordingly named Pennsylvanian. In that state, however, the marine record is very poorly developed and of little value in correlating the marine record that is so abundantly developed throughout two-thirds of western North America.

The Pennsylvanian seas submerged great parts of the continent, coming in from the southwest, spreading northward through the Cordilleran region, and eastward over Texas and Oklahoma, and overlapping the land northward into Nebraska and eastward into Pennsylvania. The submergence was most extensive in Middle Pennsylvanian time, when about 30 per cent of North America was again under the sea. During the greater part of the period, the sea-level in the eastern half of the United States was decidedly oscillatory, due to local warpings of the land, and in Acadia there was much local mountain making. In the East the Coal Measures are largely a series of interbeddings of finer shallow marine and brackish-water sediments with coarser ones of fresh waters. A final regression of the seas began late in the period, and they lingered longest west of the Mississippi and south of the Missouri rivers, retreating more and more to the southwest in Late Pennsylvanian time.

The most striking feature of the Pennsylvanian strata in this country and Europe is the fact that they contain the most valuable known accumulations of coal.

In the Maritime Provinces of eastern Canada, the Pennsylvanian is well developed and usually of very great thickness; it is all of terrestrial origin. The celebrated Joggins section of Nova Scotia is 13,000 feet in depth, with some workable coal beds. These very thick sequences of strata, with their local coal basins, were laid down in valleys between a series of narrow mountain ridges that were made here during Pennsylvanian time by block faulting. The Windsor Disturbance, as we have seen, accentuated the older Acadian folding, and then followed a long time of faulting accompanied by severe earthquakes; as a result of this faulting, Nova Scotia particularly was broken up into a series of parallel rising blocks with sinking ones between, making intermediate valleys into which the wash from the mountains was carried and quickly accumulated.

In the Appalachic basin east of the Cincinnati arch, and in the greater Central Interior sea to the west of this axis and extending into Nebraska, Kansas, Oklahoma, and central Texas, the formations have alternations of marine deposits with coal accumulations (see Pl. 18, Map 2). It was in these areas, therefore, that the sea-level was most oscillatory, and here workable coal is of very wide occurrence. In the Appalachic basin the mass of strata is not only thicker, but also coarser, consisting, in general, of sandy shales and sandstones with the marine and calcareous zones inconspicuous or absent, the marine zones vanishing eastward. Here also the coal accumulations are thicker, as the swamps were of greater areal extent, lasted longer, and were less often under the influence of the sea.

The essentially muddy and sandy marine deposits of Pennsylvanian time in eastern Kansas thin out into Nebraska and Iowa but increase southward into a tremendously thick series of sandstones and sandy shales with workable coals. West of Little Rock, Arkansas, into south-

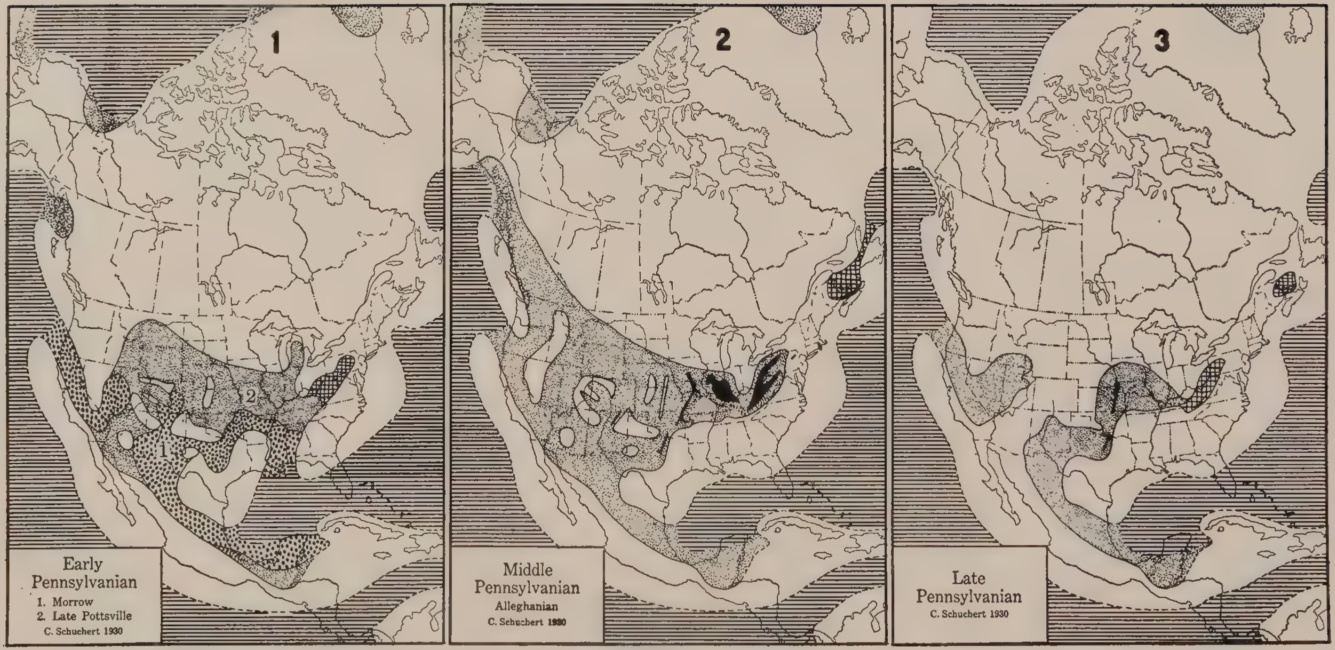


Plate 18. — Paleogeography of Pennsylvanian time.

Epeiric seas dotted; oceans ruled. Fresh-water deposits cross-ruled; coal-making swamp areas in solid black. Note in Map 2 that the main coal beds are in areas of the sea (= paralic coals), and the lesser ones in basins of fresh-water deposits (= limnetic coals).

Note in these maps and those of Plate 21 the vanishing of the Appalachic geosyncline and of the eastern interior seas, a change prophetic of the rising of the Appalachian Mountains, illustrated in Map 3 of Plate 21.

east Oklahoma occurs one of the thickest known series of Pennsylvanian strata, with a depth of between 20,000 and 25,000 feet.

These thick Pennsylvanian beds form a part of the sediments accumulated during Paleozoic time in the Ouachitic geosyncline, the trough that we saw coming into existence in Middle Cambrian time along the Mexican border, and extending eastward at times to connect with the Mississippi basin west of the Cincinnati geanticline. This trough had been kept supplied with coarse sediments by the rising borderland of Llanoria to the east and south, and by Siouia on the north (see Pl. 3). In Middle Pennsylvanian time, the maximum of submergence in the eastern end of the trough was reached (about 30,000 feet), and movement in the reverse direction began, folding the thick mass of sediments into mountains (the foreshortening of the trough is about one-half) and then overthrusting the western part of it to the north many miles. The Ouachita Mountains so made extend west of Little Rock for 220 miles into Oklahoma, with an average surface exposure of 50 miles and a greatest present elevation of 2750 feet.

The fossiliferous marine character of the later Pennsylvanian beds of Nebraska and Kansas gradually alters more and more toward Oklahoma, and in great part changes into the widely known red beds of that state, Texas, and the southern Great Plains country (see Pl. 18, Map 3). These are either of Late Pennsylvanian or Early Permian times. With the appearance of the red deposits, not only do the marine fossils largely disappear, but thick beds of salt and gypsum occur. On going southward in Texas, the amount of gypsum becomes less, the red beds yield very interesting amphibian and reptilian remains, and the time is Early Permian.

In the Cordilleran region, the record is very different from that of the eastern portion of the continent. In the area of Siouia (see Pl. 18), wherever Pennsylvanian formations are known — and they are here widespread — they are as a rule limestones of normal marine waters, and only in New Mexico and southeastern Colorado is there an alternation of this condition with that of coal making and the accumulation of detritals.

Along the Pacific border from northern California into arctic Alaska, the limestones and calcareous shales of the Pennsylvanian and Early Permian are interbedded with much extrusive volcanic material. The calcareous deposits commonly abound in fossils unrelated to those found elsewhere in North America, showing that here the North Pacific faunas prevail.

Coal. — Coal is a compact mass of plants, greatly altered through decay, the end-result of which is mainly carbon. The first stage of accumulation and decay is the formation of peat, which is explained on pages 146–147 of Part I. The transformation of peat into the various kinds of coal is the result of physical and chemical processes resulting from deep burial and great pressures during long periods; these bring about the further escape of the water and carbon dioxide and leave greater and greater amounts of fixed carbon. Anthracite coal, for example, which has 90 to 95 per cent of fixed carbon, almost invariably occurs in regions where the strata are much squeezed and folded, as in the mountain sections of Pennsylvania; and where the strata are still more greatly deformed, as in the Rhode Island field, the coals are graphitic, consisting wholly of fixed carbon.

Geologists were long divided as to the source of the plant material stored in coal beds. Did it grow where the coal is found (growth *in situ* theory), or was it drifted by streams to the place of burial (drift theory)? It was again Sir William Logan, of the Canadian Geological Survey, who solved the problem by showing that the great majority of coal beds are made of plants that grew in peat swamps and formed the coal where it is found. In a Welsh coal mine that he was operating in 1840, he found that at least eighty coal seams were each underlain by an old and somewhat sandy soil, now a tough and bleached fire-clay — the " under-clay " of the miners. This clay is full of the confused and tangled roots (*Stigmaria*) and even the stumps of erect trees (lepidodendrids and calamites). After he returned to this continent, Logan demonstrated the same condition in the anthracite coals of Mauch Chunk and Wilkesbarré, Pennsylvania, at Horton Bluff, Pictou, and the Joggins of Nova Scotia, finding at the last named place 76 coal beds and 90 underclays in a thickness of 14,570 feet of Carboniferous strata.

In 1926, the soft (bituminous) coal mined in the United States amounted to 573,367,000 tons, valued at the mines at $1,183,412,000. The anthracite output (practically all from Pennsylvania) for the same year was 75,390,582 tons, valued at $474,164,000. The number of men employed in the coal industry is about three quarters of a million. From the earliest record (1814) to the end of 1900 the United States had produced 4,470,000,000 tons of coal, and by the end of 1926 the total had risen to 17,473,772,000 tons. The total amount of coal in the United States still within 3000 feet of the surface is estimated at about 3,540,000 million tons.

Petroleum. — Just as coal is the end-result of plant accumulation, in the same way petroleum is made by nature from the remains of both plants and animals buried in sediments under seas or in saline lakes (Green River, Wyo.). Petroleum and natural gas are mixtures of carbon and hydrogen, and hence are called hydrocarbons. Forming at the times when the marine strata originated, the hydrocarbons are stored away in sediments of various kinds with mud in them. They are subsequently freed as liquids or gases from these mother oil strata by the ground waters which are circulating under great pressures, and by these waters are carried into porous or cavernous formations, mainly sandstones. The rocks storing the hydrocarbons are tapped by wells drilled into them at depths between 500 and 8000 feet or more, and the great pressures of the entombed gases drive the oil to the surface.

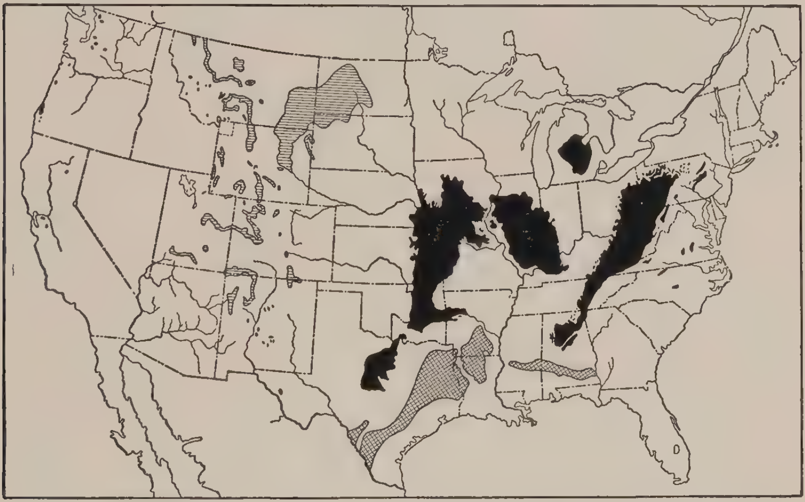


Fig 72. — Known distribution of coal in the United States. Black areas, coals of Pennsylvanian age, except in Virginia and North Carolina, where the eastern areas are of Triassic time. Areas with horizontal lines, in the Rocky Mountains country, coals of Cretaceous age. Areas with diagonal lines, coals of Cenozoic time. U. S. Geol. Surv.

Between 1859 and 1925 no fewer than 687,000 wells were sunk in this country, and of these about 20 per cent proved to be dry holes. The number of producing wells in 1926 was listed at 318,600. The yield in that year had risen to the astonishing sum of 770,874,000 barrels, with a value of $1,447,760,000; this was about 70 per cent of the world's production. The production for 1929 exceeded 900,000,000 barrels.

Life of the Mississippian

The *marine invertebrate* life of the Mississippian period presents nothing of particular interest, save for the abundance of the beautiful feather-stars or crinids (page 54), which resemble plants so closely that they are often called sea-lilies. Their remains occur in such great numbers at certain localities as to make limestones a hundred feet

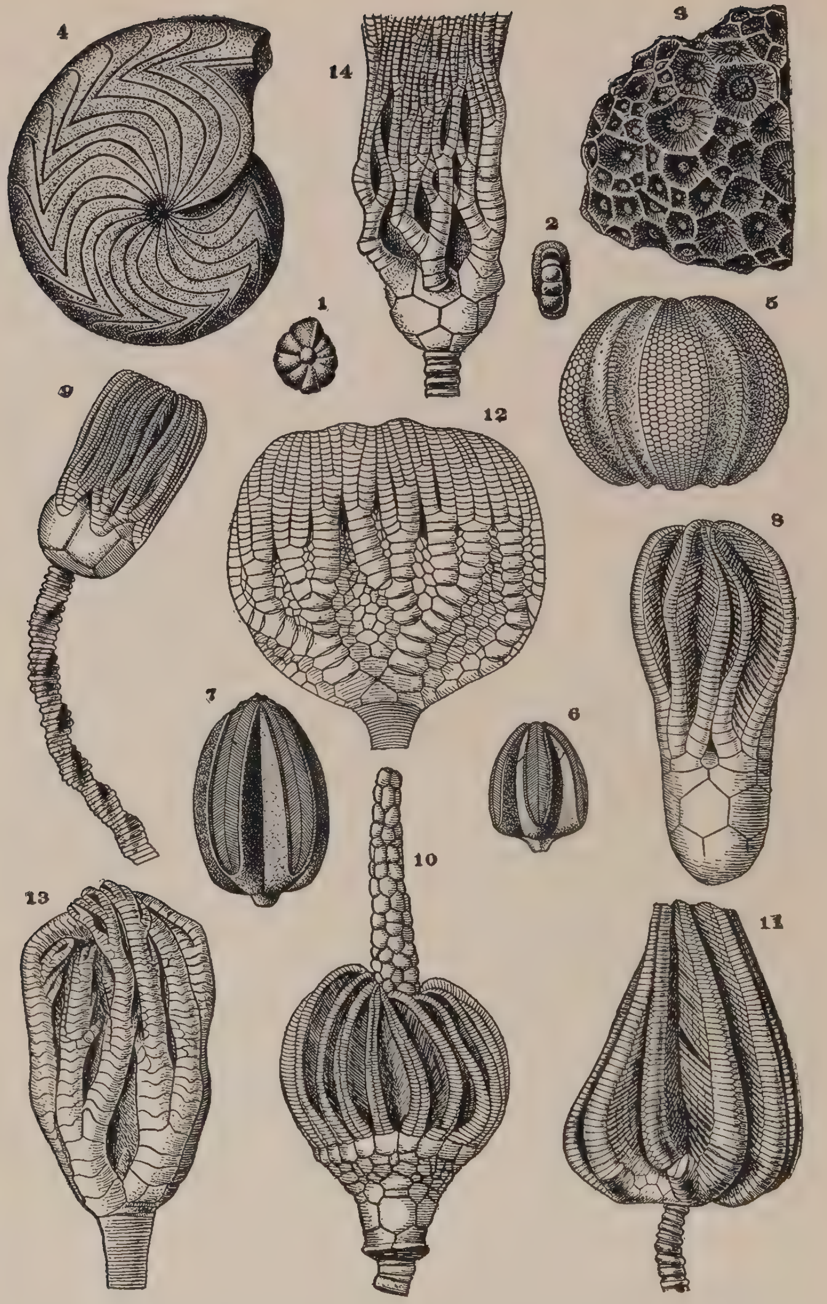


Plate 19. — Mississippian Protozoa (1, 2), reef-coral (3), goniatid (4), sea-urchin (5), blastids (6, 7), and crinids (8–14, 9–11 camerate).

Figs. 1, 2, *Endothyra baileyi*, × 9; 3, *Axinura canadensis*, × ½; 4, *Brancoceras ixion*, × ½; 5, *Melonechinus multiporus*, × ⅓; 6, *Pentremites conoideus;* 7, *P. elongatus;* 8, *Agassizocrinus dactyliformis*, × ⅔; 9, *Platycrinus symmetricus;* 10, *Batocrinus pyriformis*, × ⅔; 11, *Agaricocrinus bullatus;* 12, *Forbesiocrinus wortheni*, × ⅔; 13, *Onychocrinus ramulosus*, × ⅔; 14, *Cyathocrinus multibrachiatus.* In the main after the Indiana State Survey.

thick, the dismembered stems, arms, and bodies lying crowded together in an interlacing mass (Fig. 73).

Two other related groups of echinoderms were also especially well developed in the later part of the period. These were the blastids (*Pentremites*, Pl. 19, Figs. 6, 7), which are guide fossils to the marine deposits of this time, and in places are so common that geologists have called the beds Pentremital limestones; and, associated with them, though far less common, the equally characteristic sea-urchins known as *Melonechinus* (melon-urchin, see Pl. 19, Fig. 5).

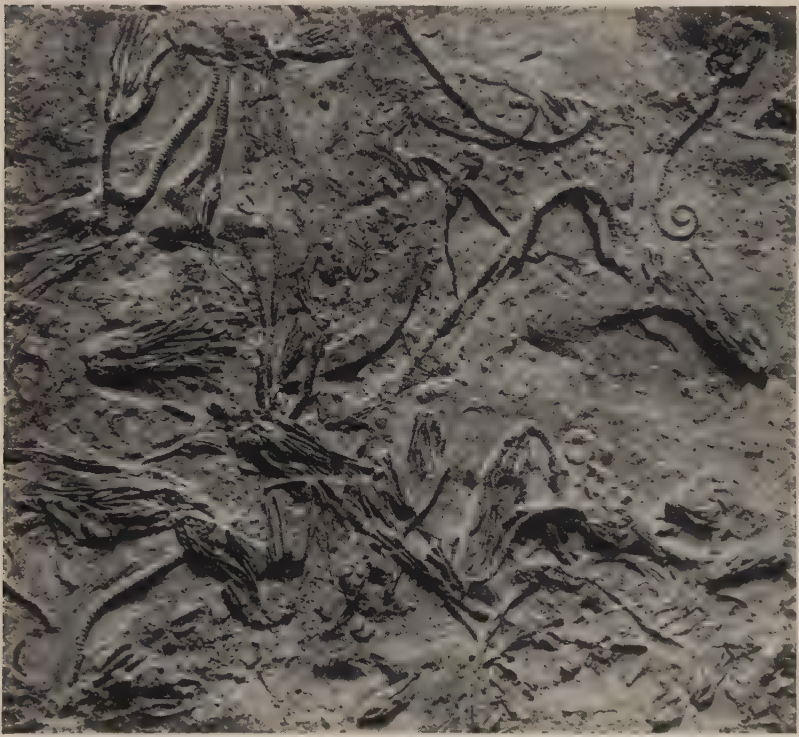


FIG. 73. — A limestone slab replete with crinids (*Melocrinus paucidactylus*), from the Lower Devonian at Jerusalem Hill, Litchfield, New York. Similar crinid limestones are common in Mississippian strata. New York State Museum, Albany.

Other kinds of invertebrates abundant in the Mississippian seas were the bryozoans, cup corals, and brachiopods; one brachiopod genus, *Productus* (Pl. 20, Figs. 5–11), was, in fact, so common and conspicuous in the seas of all three Carboniferous periods that they are often called Productus seas. Among cephalopods, the nautilids were no longer so prevalent as they were in earlier times. Trilobites were almost gone.

Among the *marine vertebrates*, large sharks of the shell-feeding type were becoming more and more plentiful during Mississippian time, for their flat, crushing teeth and large fin spines are often abundant (Fig. 74). In the American Devonian there are 39 species of shell-feeding sharks, in the Mississippian 288, in the Pennsylvanian 55, and in the Permian 10. It is apparent, therefore, that there was a very rapid evolution of these ancient sharks in the Mississippian, when they were the dominant marine fishes, with a quick decline during the later Paleozoic. Their history is the same in Europe.

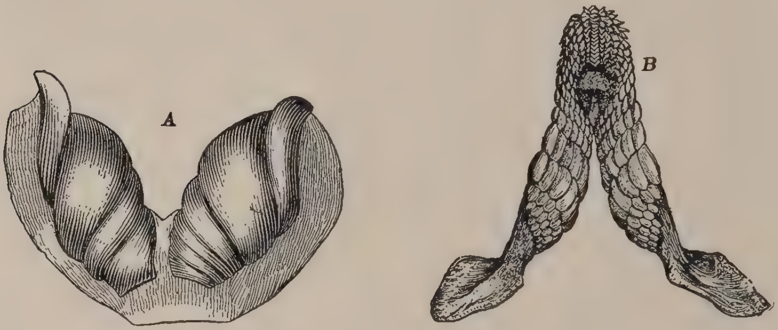


Fig. 74. — Teeth of primitive sharks adapted for crushing shellfish. *A*, jaw with two large tooth-plates (*Cochliodus contortus*, of Mississippian age). *B*, upper jaw, with many teeth, of living Port Jackson shark (*Cestracion philippi*). British Museum (Natural History).

Of Mississippian *land life*, little is known in North America. Plant remains occur in the deposits of the Appalachic trough in Pennsylvania (Pocono series) and the red Mauch Chunk beds of the same commonwealth record many amphibian tracks, one of which (*Palæosauropus*) has a 13-inch stride. Of the makers of these tracks, however, nothing is known.

Life of the Pennsylvanian

The *plants* of the Carboniferous periods have a special interest because of the rôle they play in the coal-making that went on during this time. With the Pennsylvanian, land plants began to be common, and the swamp floras were then luxuriant, large, and varied (Fig. 75); in many respects they were " one of the most wonderful and luxuriant, though not the most varied, floras the world has known." Furthermore, these floras, and the land animals as well, were not only very much alike in the different lands of the northern hemisphere, but there was a marked

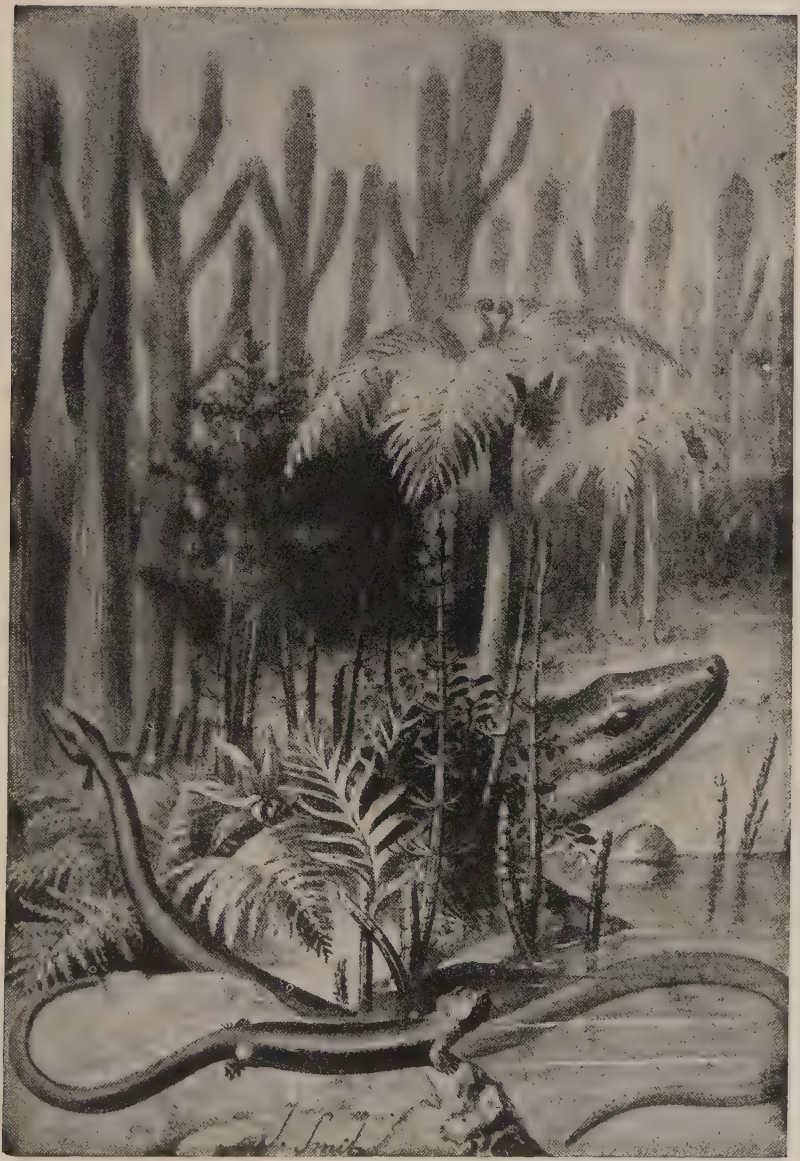


FIG. 75. — Pennsylvanian flora and amphibia, as restored by J. Smit. In the background are seal-trees (*Sigillaria*), with tree-ferns and conifers in the middle distance. In the foreground are rushes (calamites) and seed-bearing fernlike plants. Amphibia are represented by a small four-limbed microsaurian (*Keraterpeton*), a large-headed form (*Loxomma*), and a snakelike, gill-bearing stegocephalian (*Dolichosoma*, from Linton, Ohio). From Knipe's *Nebula to Man.*

similarity even between the floras of the two hemispheres during the greater part of Pennsylvanian time. In other words, the floras, and to a lesser extent the faunas, were cosmopolitan, and their similarity was undoubtedly due to equable climates and easy migration across the extensive east-west continent known as Holarctica, which combined the lands of the northern hemisphere. Their distribution was further facilitated by the fact that most of the plants had spores, or microscopic reproductive germs, which could be widely blown about by air currents.

The coal floras, from which upward of 3000 species have been described, were conspicuous for their club-mosses or scale-trees, a sort of evergreen unlike anything now living. Some of these attained great size. One trunk found prostrate in an English coal mine was 114 feet long up to the first branch and the branching continued through another 18 feet. They were not stiff trees and probably were swayed much by the winds. These spore-bearing club-mosses made swamp forests near sea-level, and developed into many species.

Another remarkable group were the gigantic calamites, living segregated like the modern cane brakes and bamboo thickets. The floras also included many fernlike forms, both delicate and hardy, some of which were climbing in habit, while others grew into majestic tree-ferns.

Shades of green were the dominant color, and the monotone of the verdure was nowhere enlivened by bright flowers. Flowers were present, however, but of a low order, insignificant in size and doubtless unattractive. Probably more than one-half of the flora was spore-bearing and we may safely regard most of the more common plants of the Coal Measures as seedless. Fertilization was not yet accomplished through the aid of honey- and pollen-eating insects as is so general among the living flowering plants of the present, but was brought about by the rains and winds. The trees of this wonderful flora are described in more detail in Chapter V.

In the marine waters of the Pennsylvanian, the *invertebrate* life was not only prolific but highly varied (see Pl. 20). It was, moreover, cosmopolitan. Brachiopods are the common fossils in this country, but their places were being taken more and more by bivalves reminding one of living scallops and long-shelled clams. Of greatest interest were the coiled cephalopods, destined to rapid development in Permian times (see Fig. 76).

On the bottoms of the Pennsylvanian seas lived great quantities of fusulinids, warm-water protozoans that made small spindle-shaped bodies of calcium carbonate (Pl. 20, Figs. 1, 2). These at times built up thick limestones, and were common even in Spitzbergen above 76° north latitude.

As a result of the equable climate and great development of the floras, the Pennsylvanian was the time of giant insects, the largest ever known. The maximum size was reached by ancestors of the dragon-flies, one of which, found in the Coal Measures of Belgium, measured 29 inches across the wings. The period well deserves the title of the Age of Cockroaches, since more than 800 kinds are known from its rocks. They were mainly carnivorous, and as a rule large, several attaining a length of 3 to 4 inches — " aristocrats of the insect world."

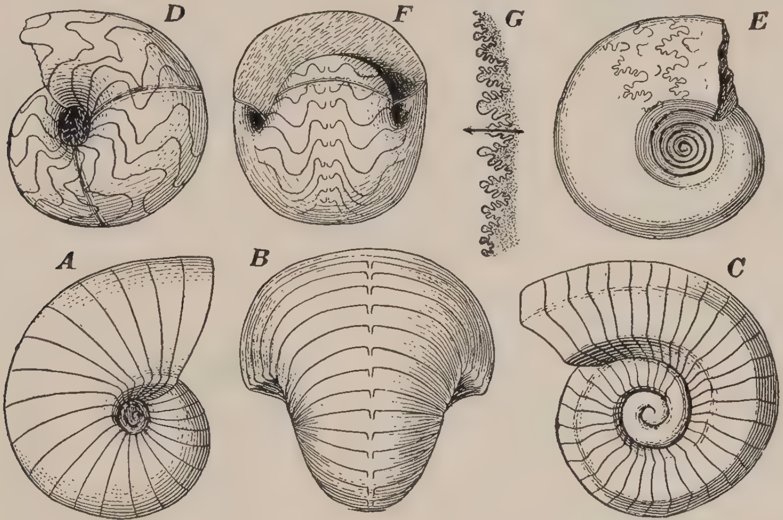


Fig. 76. — Characteristic cephalopods of the Pennsylvanian. *A–C*, nautilids; *D*, *F*, goniatites; *E*, *G*, ammonites. *A*, *B*, *Solenocheilus kentuckiense; C*, *Domatoceras militarium; D*, *F*, *Glyphioceras incisum; E*, *G*, *Waagenoceras cumminsi.* Texas State Geol. Surv.

In the Pennsylvanian rocks scorpions are again known, which, ancient as they are, much resemble those of modern times. Associated with them were many forms of thousand-legs and rather stout spider-like animals. The first air-breathing land snails appear in the middle of the period, the greatest number of their remains coming from the hollows of the fossil tree stumps in the Joggins coal beds of Nova Scotia. Fresh-water invertebrates were also on the increase, especially in the form of bivalves (clams), though smaller and unlike those of our modern rivers and lakes.

The vertebrates of the Pennsylvanian are discussed in connection with those of the Permian, on page 185.

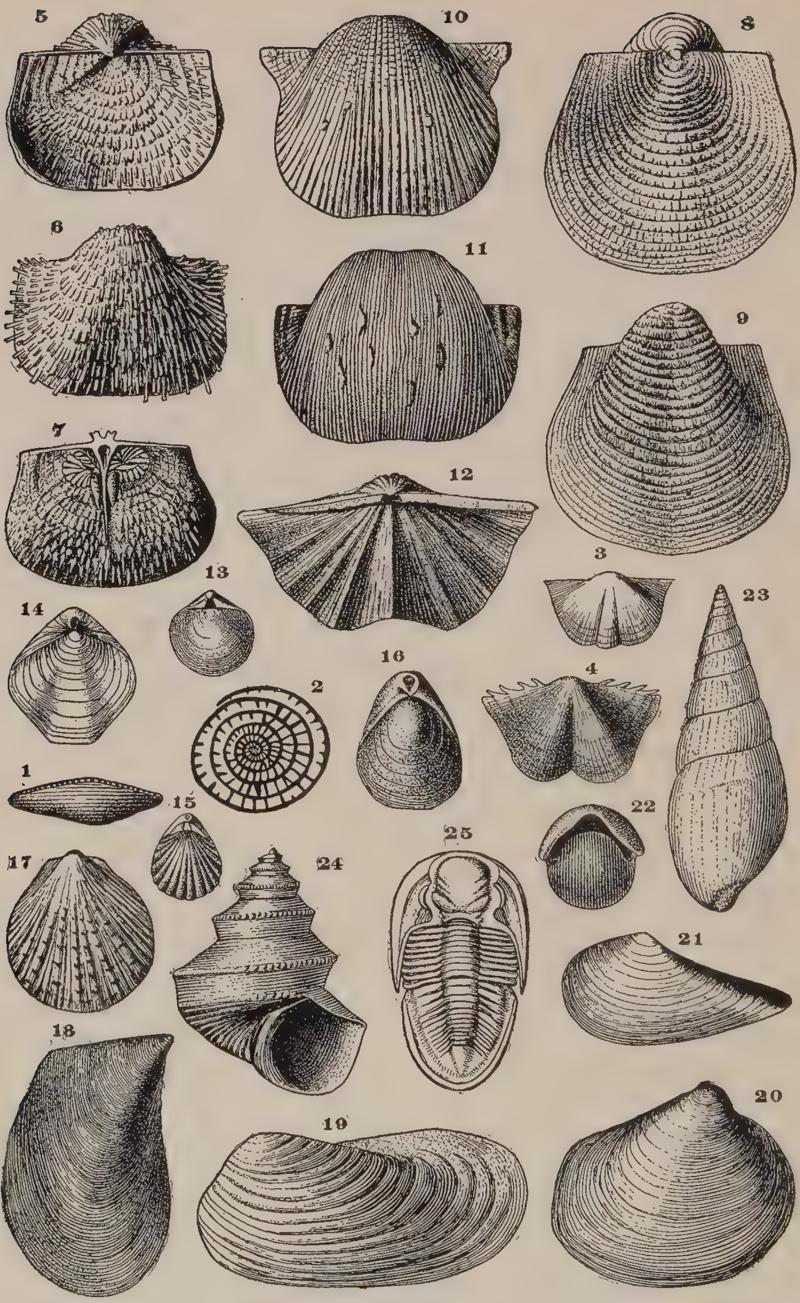


Plate 20. — Pennsylvanian Protozoa (1, 2, Fusulinidæ), brachiopods (3–16, 5–11 productids), bivalves (17–21), and gastropods (22–24), and one of the last trilobites (25).

Fig. 1, *Triticites secalicus*, × 2; 2, same cut through center, × 8; 3, *Chonetes mesolobus;* 4, *C. verneuilianus*, × 2; 5–7, dorsal and ventral valves, and dorsal interior of *Productus nebraskaensis;* 8, 9, *P. punctatus*, × $\frac{2}{3}$; 10, *P. semireticulatus;* 11, *P. cora*, × $\frac{1}{2}$; 12, *Spirifer cameratus*, × $\frac{2}{3}$; 13, *Ambocœlia planoconvexa*, × 2; 14, *Composita subtilita*, × $\frac{2}{3}$; 15, *Hustedia mormoni;* 16, *Dielasma bovidens;* 17, *Pseudomonotis hawni*, × $\frac{1}{2}$; 18, *Myalina subquadrata*, × $\frac{1}{2}$; 19, *Allorisma subquadratum*, × $\frac{1}{2}$; 20, *Schizodus harii;* 21, *Leda bellistriata*, × 3; 22, *Euphemus carbonarius*, × $1\frac{1}{2}$; 23, *Soleniscus fusiformis;* 24, *Worthenia tabulata;* 25, *Phillipsia major.*

CHAPTER XIV

PERMIAN TIME: THE TRANSITION FROM PALEOZOIC TO MESOZOIC

Transition periods have a peculiar interest, wherever we find them — in individual history, in race history, in Earth history. The leaven of change is then more actively at work, and alongside of the established order we catch glimpses of that which is yet to be.

The period bridging over the span from Proterozoic to Paleozoic has left us no record, and of its events we can only surmise from what we see already accomplished at the outset of the Paleozoic. Of the Permian, however, closing period of the Paleozoic, we have a fullness of record that has been long and widely studied in many continents, its rocks being among the very first to attract attention, because of their copper and salt in Germany. Now we have a wealth of facts from the Ural, one of whose districts (Perm) gave the period its name, from Germany, from India, from China, and from Africa. Fullest of the Permian records, however, is that of our own Southwest (Texas, New Mexico, Arizona), where recent work is bringing to light a marine Permian sequence that will become the standard for the world.

The underlying cause for the changes that seem to come at an accelerated rate in the Permian was world-wide mountain making. This crustal unrest was foreshadowed already in the earlier periods of the Carboniferous, with mountains rising in Mississippian time and even more widely and more often in the Pennsylvanian. The culmination came in the Permian, when all the continents were rising or the ocean floors sinking. Such marked rearrangements in land and sea brought on great climatic changes, the rugged rising lands becoming drier and drier and the temperature cooler and cooler until late in the Middle Permian ice-sheets covered immense areas in the southern hemisphere. Later on these continental ice-sheets vanished, but the lands remained high and rugged far into Triassic times, and under these conditions the plants and animals were forced into a mighty struggle to adapt themselves to the vastly altered environment. Nature's weeding out of the unfit was in full swing, not only with individuals but with families and with larger groups as well.

Even in the seas, which are the last to feel the effects of climatic change, and whose conditions are therefore constant over long periods of time, the great cooling drove out of existence many of the prominent groups and in their places ushered in others better fitted for the new conditions. The trilobites, for example, succumbed completely; the class had been dying out ever since the Silurian, and there were but few scattering ones left in the Permian. The brachiopods were more fortunate, and although the mortality was high among some of them (orthids, strophomenids, productids), two other stocks (rhynchonellids and terebratulids) burst into great variety in the Mesozoic. Coming rapidly to the forefront were the alert cephalopods (ammonites), which showed astonishing variety in the Permian and were destined more than ever to dominate the marine invertebrate world in the Mesozoic.

The animals of the lands, more accustomed to changing environments, stood the strain better. The sluggish Carboniferous amphibians met the challenge of aridity in part by evolving into reptiles and thereby requiring a water habitat at no stage in their development. Some, however, lived on with little change in the stream courses. The insects developed resting stages to tide them over the stress periods. The plants forsook largely the antiquated spore-bearing habit and learned to use instead the more effective one of reproduction by seeds, embryos that were protected and supplied with food while they lay dormant.

All these adaptations mean that the organic world of the Mesozoic is a different one, linked to that of the Paleozoic by a few hold-over forms, but bearing in the main a distinctly new impress, marked by a versatility and quickness of wit that are lacking in the Paleozoic, but are still inferior to those of the Cenozoic: in other words, medieval.

Permian Geography

(Plate 21)

Only during the past twenty years has it become clear that probably the longest and most fossiliferous marine Permian sequence anywhere in the world occurs in western Texas, New Mexico, and Arizona. This region will in consequence become the standard for correlation, since in no other continent is the whole of the Permian fossiliferous, with marine forms from bottom to top. As these southern interior seaways derived their waters in least amount through the Mexican geosyncline and in greatest volume from the Pacific, and finally from the Arctic down through the Cordilleric trough, we will have to abandon our usual order in handling the geographic distribution and, beginning with the New Mexico-Texas area, follow the transgression to the northeast and lastly to the west and north.

In the Marathon area of western Texas the sea of Permian time was

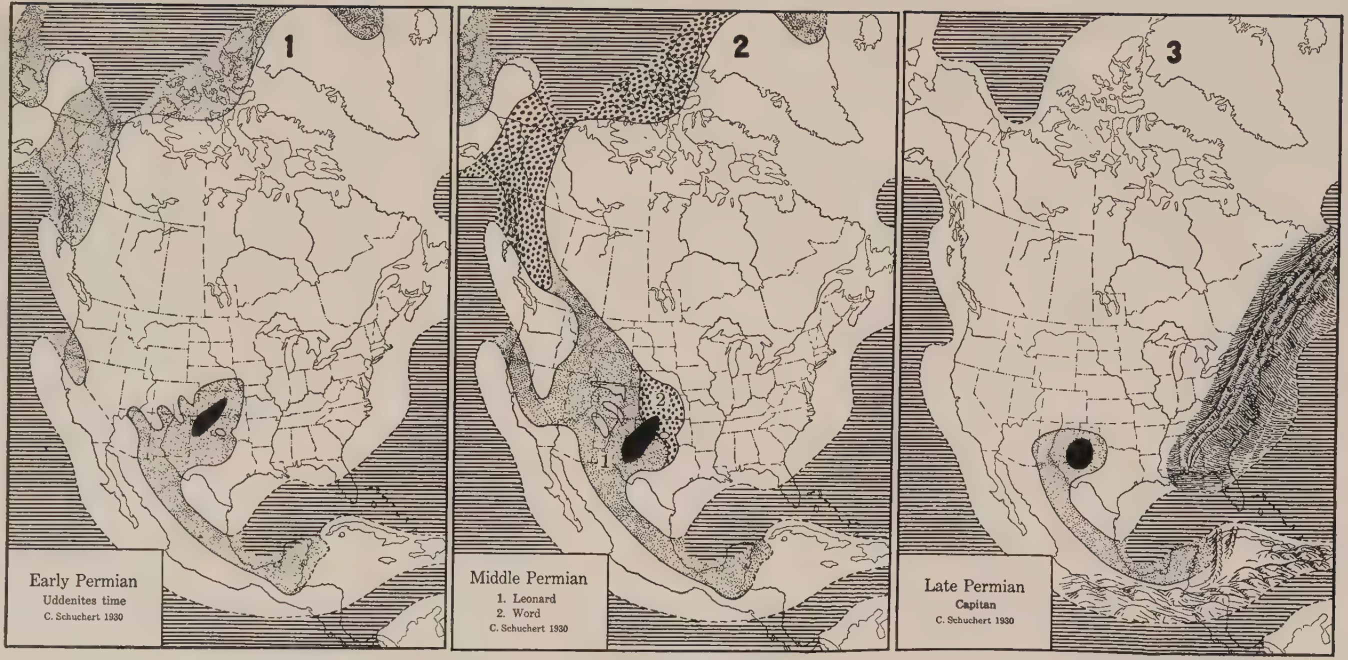


PLATE 21. — Paleogeography of Permian time.

Epeiric seas dotted; oceans ruled. Areas of salt and gypsum in black. Note in Map 3 the regions of mountain making.

present during the whole of the period, and deposited here upward of 6000 feet of limestones and dolomites with very little of shales and sandstones. In the Glass Mountains, which make the northwestern highlands of the Marathon basin, the Early and Middle Permian limestones are fossiliferous throughout, but the younger dolomites are almost devoid of fossils because of the change these strata have undergone from their original limestone nature. In the Guadalupe Mountains, 100 miles to the northwest of Marathon, however, the equivalent Capitan limestone has the necessary fossils to make clear the evolution of the marine faunas.

As one proceeds to the north and northwest from the Marathon area and the old land Llanoria to the south and southeast, the later Permian dolomites mentioned above change into anhydrite and salt deposits, showing that the inland sea of the southwest lay under an arid climate, evaporating away the water and leaving the salts in great thickness. To the northeast these deposits of the later Permian thin away and are absent in central Texas, and farther east throughout the United States there was land at this time and ever afterward. The older Permian sea, however, spread across central Texas, Oklahoma, and Kansas, into Nebraska and Iowa, and there laid down a series of marine and brackish deposits that terminates in 1000 feet of red beds (Cimarron). To the west the marine beds pass into brackish and fresh-water deposits having the last of the Pennsylvanian spore flora, a world of new insects, and a wonderful, newly arisen, alert, and varied reptilian fauna, while the intermediate river distributaries abounded in fish and quite an assortment of amphibians.

In the previously mentioned interior basin, in Kansas and Oklahoma, the Pennsylvanian seas are believed to have lingered into Permian time. To the eastward, however, this seaway took on more and more the nature of an estuary, and in southeastern Ohio, West Virginia, and westernmost Pennsylvania, that of a delta-lagoon, in which there accumulated reddish deposits bearing land plants. Here and there occur brackish-water organisms, and in places are thin earthy limestones with minute shells, mainly gastropods, which appear to be of fresh-water habitat. These scattering fossils are of the well known *Dunkard series.*

To the north of the Texas-New Mexico marine area as far as Montana the Lower and Middle Permian formations pass into the well known red beds that have thin zones of anhydrite, while in northern New Mexico and Colorado the red beds are much thicker and coarser, with local marine dolomites. The coarse materials and conglomerates here are of local origin, brought from a newly arisen area to the west of them, the San Luis Obispo mountains of Siouia, made in Pennsylvanian time and re-elevated in the Permian. On the other hand, the red beds of central Texas and Oklahoma came from uplifted Llanoria to the southeast. These uplifts completely changed the geography of the area now occupied by the southern Rocky Mountains.

Turning now to the Pacific side of the continent, the Permian picture becomes wholly marine, the seas advancing into the troughs as they did in Pennsylvanian time. In the Middle Permian the Cordilleric trough was awash from Mexico to the Arctic. Curiously, this flood evidently came in from the north, carrying cool-water marine invertebrates as far south as the Grand Canyon region and thence this life penetrated, less and less, eastward. Among its deposits were the widespread Phosphoria formation of the Rocky Mountains (Idaho, Wyoming, Montana), which yields phosphates in quantity and also holds petroleum in its oil shales; and the Kaibab limestone, which rims the Grand Canyon. The Canyon, in fact, offers a fine Permian section, ranging from the marine Kaibab down through the Coconino of dune-sand origin, and the red Hermit and Supai shales, with very significant land plants. These in turn rest on the Mississippian Redwall limestone. The Pennsylvanian seas apparently did not cover the eastern Grand Canyon region, although they almost encircled it.

In the preceding paragraphs attention was directed to the red beds of different ages and of vast extent in the medial region of this country. Such widely spread red formations indicate the presence of arid or desert climate, and their evidence is strengthened by that of the great *salt beds* of Texas, New Mexico, Oklahoma, and Kansas. In the last named state, at Hutchison and Lyons, salt has been mined for many years, and the salt deposits are known to have a thickness of between 200 and 400 feet in an area of at least 7000 square miles. The largest underground deposits are in westernmost Texas and northeastern New Mexico, where the Late Permian salt beds cover at least 100,000 square miles — the largest salt area of the world. In Germany the seas of Upper Permian time also laid down tremendous amounts of salt and gypsum, so that the Permian is now known to have been the time of greatest saline deposition in all geologic history.

Appalachian Revolution

The mountain making of the Pennsylvanian, continuing into the Permian, culminated in the Appalachian Revolution. The area of deformation caused by this orogeny was greater than that of any other crustal movement in eastern North America, extending from the latitude of Boston and the Catskills to southern Alabama, a distance of 1500 miles, while the central and western end of the Ouachitic trough was folded into mountains late in the Permian that reached for 1200 miles across Texas and northern Mexico.

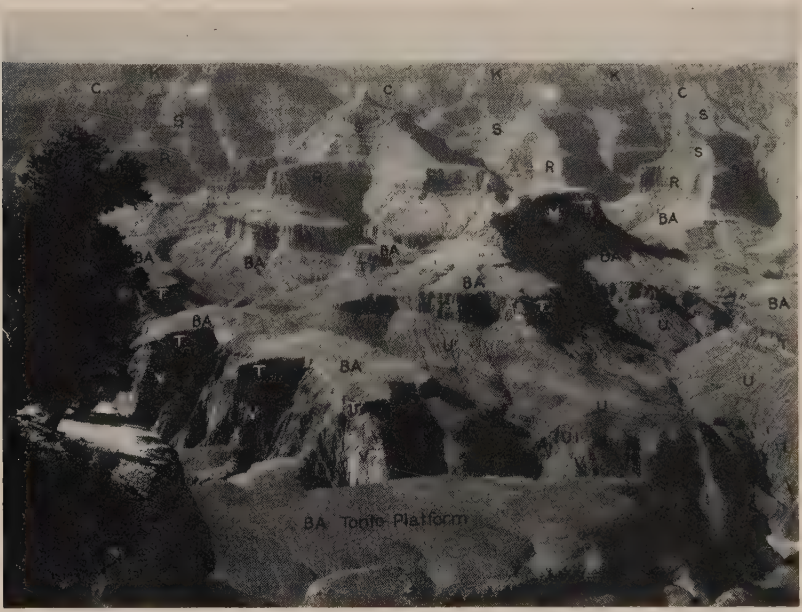


FIG. 77. — Grand Canyon, from Yavapi Point. Note how the ancient beds of the Unkar group, to the right, have been tilted from their original horizontal position so that they now lie at an angle with the beds above (Grand Canyon disturbance). In other parts of the Canyon, the Unkar mountains have been worn entirely away, and the Cambrian rocks lie directly upon the granite (Archeozoic) of the inner gorge. Photograph from Fred Harvey.

K =	Kaibab limestone		Permian
C =	Coconino sandstone		
S =	Supai sandstone and shale		
R =	Redwall limestone		Mississippian
M =	Muav limestone		Cambro-Ordovician
BA =	Bright Angel shale	Tonto	
T =	Tapeats sandstone		
U =	Unkar group		Proterozoic
V =	Vishnu schist		Archeozoic

In the Appalachian area, soon after Lower Permian time, mountain making was becoming the dominant feature, and due to this folding movement of the formerly sinking geosyncline the interior seas were completely blotted out, *never to return to eastern North America.* In other words, the Appalachian geosyncline, from this time on, was no longer an area of subsidence, offering access to invading seas, but a rising one that was to persist until to-day. The Acadian trough, it will be remembered, had been similarly destroyed by the Devonian mountain making, as had the Arkansas-Oklahoma end of the Ouachitic-Sonoric trough in Late Pennsylvanian time. In the Appalachian area, the open folds made in the rocks during the Pennsylvanian were closed by the great pressures from the Atlantic and finally overturned and overthrust to the northwest on a very large scale. In the New England States there were in many places intrusions of granitic rocks. At the same time all of the domes and axes of the eastern United States were accentuated.

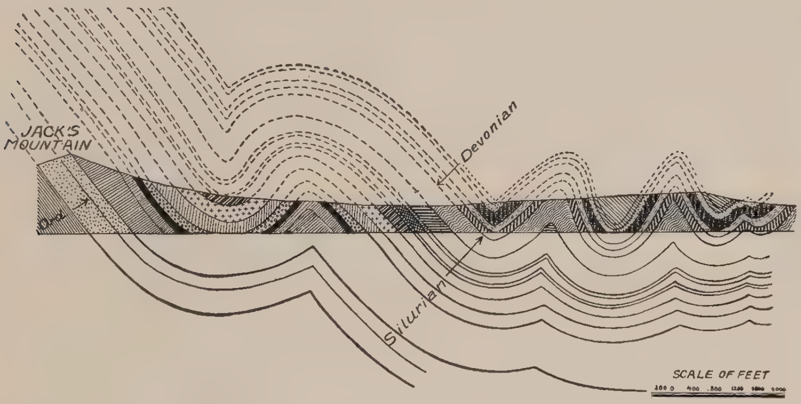


Fig. 78. — Diagram of the Appalachian folds near Lewiston, Pennsylvania. The dotted lines indicate the portion worn away, the upward curve at the left suggesting the former height of Jack's Mountain. Solid black indicates iron ore. After Lesley.

How high the Appalachians stood in Permian time is hard to ascertain, but on the basis of the folds measured in Pennsylvania it has been suggested that they may have been 5 miles high. However, as mountains rise slowly and their highest peaks are rapidly worn down during the time of their rising, it is probable that the Appalachians at no time had the grandeur of the present Himalayas. There may nevertheless have been peaks that stood from 2 to 3 miles high in Middle Permian time (see Fig. 78). Underground the folding extends from 6 to 30 miles.

The long-drawn-out Late Paleozoic revolution was one of the most critical periods for the organic world in the Earth's history, and may have been the greatest of them with respect to changing environments. Something of this change has already been stated in the opening pages of the chapter.

That the crustal unrest of the Late Paleozoic was of world significance is apparent from the many mountains that were made at this time in all the continents. In central and western Europe, the movements began shortly after the close of Lower Carboniferous time, were renewed in the Upper Carboniferous, and again in the Permian. In the heart of Europe there consequently arose a mighty chain of folded mountains, the *Paleozoic Alps of Europe*, whose stumps of massive rocks may be seen in Germany, France, Belgium, England, and Ireland to-day. Mountains also arose in the Pyrenees, the Spanish Meseta, Corsica, Sardinia, and the Alps. The folding of the Urals likewise began in later Carboniferous time and attained its climax in the Permian. Even in Armenia, central and eastern Asia (Altai, Tianschan, etc.), Australia, and the Andes can be followed the traces of the mountain-making movements of this time. (See Fig. 79.)

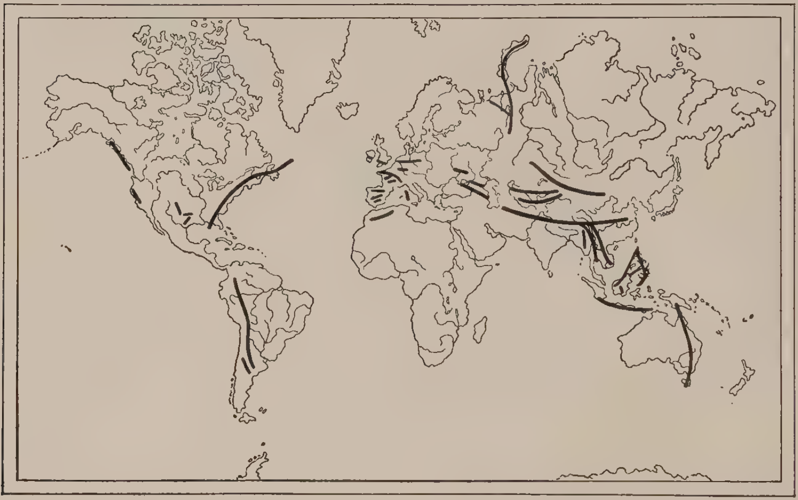


Fig. 79. — The ranges of mountains elevated toward the close of the Paleozoic: Appalachians, Andes, Paleozoic Alps of Europe, and others.

Paleozoic Climates in General

Until about seventy-five years ago, all students held that the Earth throughout geologic time had been cooling down from the original astral condition, the crust ever becoming thicker and thus radiating less and less heat, and the atmosphere therefore gradually becoming clearer, cooler, and finally cold during the Pleistocene epoch out of which we are now emerging. Then geologists in South Africa began to point out that there had been an ice age in that region in Late Paleozoic time, and this conclusion was finally confirmed beyond dispute.

All of the well known ice ages (there are four) and the times of cooling in lesser degree occurred when the Earth's surface was most rugged and the continents largest and most connected by land-bridges. They alternated with longer times of equable mild to warm and moist conditions that became more and more general as the continents were reduced to sea-level, and these long-enduring mild climates were the rule during the Paleozoic. In this era, the North American continent was also repeatedly and widely flooded by the oceans, and when these seas were most widespread, limestone was the dominant rock laid down by them, even into arctic latitudes, hence the lands must have been low, the climate warm temperate and largely moist throughout, and in consequence the seas and oceans everywhere warm and equable. These conclusions are confirmed by the abundance and nature of the life in these seas, and by none more than the very widespread Silurian corals that made reef-limestone from New York to Iowa and from Tennessee to at least the Hudson Bay country; and Silurian, Devonian, and Late Carboniferous corals were plentiful even in arctic seas. (See Fig. 56, p. 114.)

When the lands were emergent and large, as they were during the later and earlier parts of each period, and in eastern North America when the Taconian, Acadian, and Appalachian mountains were in their grandeur, the climates must have been cooler, but there is no evidence in the low lands where our fossils occur that there were freezing winters. In Alaska, however, there is evidence of local glacial conditions at sea-level during the Silurian and Pennsylvanian, and in the Early Devonian of southernmost Africa striated pebbles are common.

The problem of why climates change will be taken up in Chapter XX on Pleistocene time.

The Ice Age of the Permian. — In late Middle Permian time all of Africa and Madagascar south of 22° and 23°, respectively, was covered by ice-sheets that at their maximum were between 4000 and 5000 feet thick. The Transvaal sheet was the most extensive, moving at least 700 miles to the southwest. Eight or nine horizons of glacial rock débris derived from floating icebergs occur in South Australia above the coal beds, some of the tillites being 200 feet thick, interbedded in 2000 feet of marine strata; in India the very thick glacial deposits (Talchir) preceded the Permian submergence, and the same sequence occurs in Brazil. The old polished, striated, and grooved ground over which the glaciers moved is known in India, Africa, Australia, and South America. In North America, tillites seemingly of Permian age are known about Boston, Massachusetts, and tillites are also known to occur in different places in Alaska. For the complete distribution of these glacial deposits, see Fig. 80.

The Permian glacial formations thus occur mainly on either side of the equator from about 20° to 35° north and south latitudes, but evidence of this kind is scattering above 35° in north temperate lands. The evidence is now unmistakable that during a limited part of Permian time most of the lands of the southern hemisphere were under the influence of a glacial climate as severe as the polar one of recent times, and that, like the latter, the Permian one also had warmer interglacial periods, for coal beds occur associated with the glacial deposits in Australia, South Africa, and Brazil.

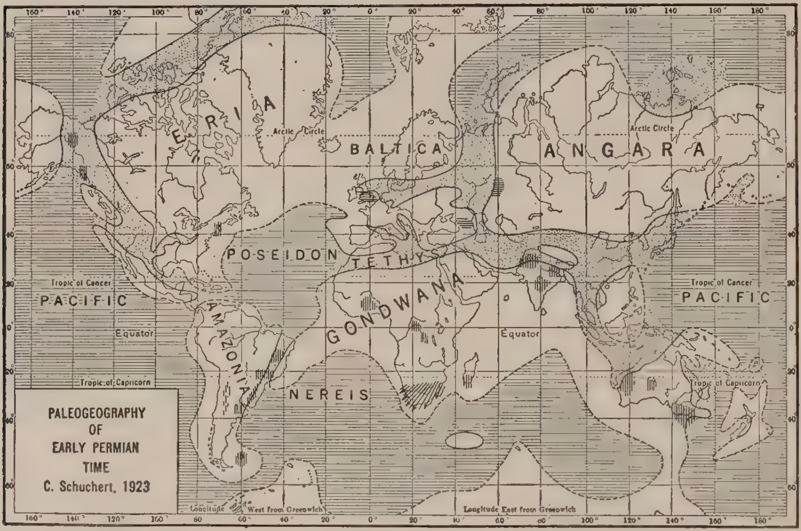


Fig. 80. — Paleogeography and areas of known glaciation of Middle Permian time. Oceans ruled, epeiric seas dotted, places of glaciation lined (vertical lines, areas of proved glaciation; horizontal lines, of uncertain glaciation). Note the transverse shape and connected condition of the continents of this time.

What brought about this great change in the climate of Permian time, and why it was, apparently, mainly restricted to the southern hemisphere are questions upon which there is as yet no general agreement.

Life of the Permian

The *plants* of the Carboniferous, luxuriating in the almost universal mild climates, had a world-wide distribution, often with identical species in the northern and southern hemispheres. This happy condition was rudely interrupted by the aridity that set in with the Late Pennsylvanian and continued throughout the Permian, and by the glaciation that affected all of the southern continents. The old floras were almost entirely destroyed in the southern hemisphere, and somewhere, probably in Antarctica, a new and hardier set of plants, dominantly seed-bearing, developed to take their places. Characteristic of this new assemblage were two rather coarse fernlike plants with simple undivided leaves growing on creeping stems (Fig. 81); these two plants, known as *Glossopteris* and *Gangamopteris*, have given their name to the flora, which appears at about the same time in Africa, Australia, Tasmania, southern India, and South America. With the new plants are found, in Brazil, a few old-timers, such as *Lepidodendron* and a single *Sigillaria*, which were either able to adapt themselves to the cold or else returned to these regions from some northern area. With them in Brazil reappeared the tree-fern *Psaronius*, with a trunk 2 feet in diameter and a probable height of 60 feet.

In North America, which was not directly affected by the Permian glaciation (although there was local glaciation about Boston), the floral history is somewhat different. The greater part by far of the ancient cosmopolitan flora died out and it was replaced by one of seed-ferns, found also in Asia. This new assemblage was the *Gigantopteris* flora, later to be replaced by the Supai flora seen in the Grand Canyon. The calamites were altering into the modern equisetums or horsetails, the cordaites gave rise to true conifers (*Walchia, Voltzia, Ullmannia;* see Fig. 82), and to the maidenhair trees (*Gingko*), a Mesozoic type of which an Asiatic species is the sole modern survivor. The many scale- and seal-trees, however, had vanished by the close of the Permian.

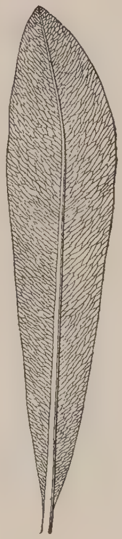


FIG. 81.—Leaf of the Permian net-veined seed-bearing *Glossopteris* (*G. indica*). From Credner's *Elemente der Geologie.*

Among the invertebrates of the Permian lands, the effect of the aridity is especially to be noted among the *insects.* For a long time there was a gap in our knowledge of the history of this now ubiquitous class, between the giant coal-forest forms of the Pennsylvanian and the essentially modern ones of the Triassic, which represent all the living orders but two. The only types common to both faunas were the cockroaches. This gap has been filled within recent years by Permian insect assemblages found in Kansas, in New South Wales, and in Russia.

The Kansas insects show plainly the influence of aridity in their much smaller size, as compared with those of the Carboniferous, and in the development, in three distinct groups, of pupal resting stages, which would carry them over times of climatic stress. Of the Carboniferous orders only a few representatives remain in the Permian, notable among them being *Dunbaria* (Fig. 83).

The older Permian *marine life* is richly represented in the Texas deposits. The fusulinids and the molluscs show a normal advance over those of the Pennsylvanian, while the brachiopods introduce some strangely specialized forms (*Oldhamina, Aulosteges, Scacchinella, Richthofenia,* etc.) such as often develop when a race reaches its senescence (Fig. 84). The trilobites were completely gone by the end of the period. Cephalopods, on the other hand, and especially the coiled ammonites, were in their Golden Age, branching out in all directions, so that the forebears of the whole horde of Triassic genera are represented. In fact, they are present in such numbers and have been so thoroughly studied that we know their development better than that of most Recent shells (J. P. Smith). This detailed knowledge of the ammonites, moreover, makes them invaluable as time guides.

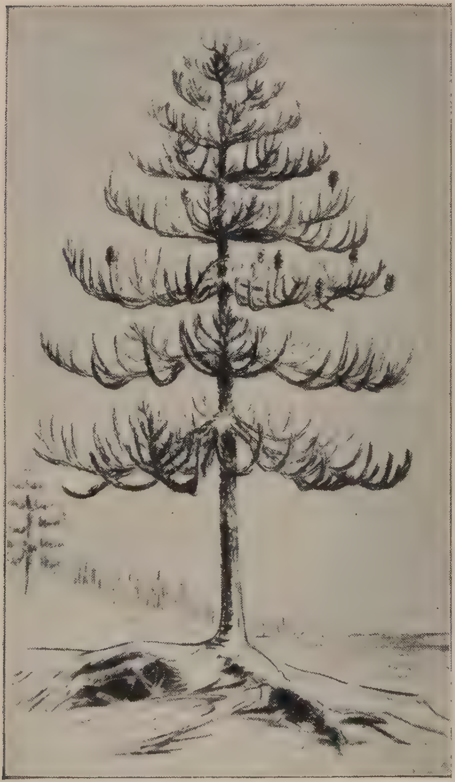


FIG. 82. — Restoration of a Permian conifer, *Archæopodocarpus germanicus.* From Weigelt's *Pflanzenreste des mitteldeutschen Keuperschiefers* (Borntraeger).

The last stand of the Paleozoic marine life was in Tethys, the greater Mediterranean, whose rock and organic records are found in the eastern Alps and the lands to the east as far as the Himalayas. In these warm waters the descendants of the Upper Carboniferous corals, brachiopods, and molluscs still swarmed in varied profusion well into Late Permian time. When the record of the marine Triassic begins, however, it shows that a great change has taken place, for now all the Paleozoic fusulinids, corals, blastids, productids, and trilobites are gone, and there is a new assemblage of more modern molluscs, echinids, and corals, the essential denizens of the medieval marine world.

Late Paleozoic Vertebrates. — The presence of *amphibians* is recorded by tracks, as we have seen, in rocks as old as the Late Devonian, but their actual skeletal remains do not appear in this country until Pennsylvanian time, although they are present in the Lower Carboniferous rocks of Scotland. The amphibians of the coal swamps of the Pennsylvanian, grouped under the name Stegocephalia (" armored head "), were a highly varied lot, ranging in size from the 2-inch-long *Eumicrerpeton* to *Eryops* with the length of an adult Florida alligator. Most of them were small creatures resembling the living mud-puppies and salamanders, sluggish, and mainly aquatic. *Eryops*, one of the best known representatives, looked like a huge tadpole, with its wide flat head and body, its short legs and its flattened tail; it might well, as Huxley says, have " pottered with much belly and little leg, like Falstaff in his old age, among the coal forests." (See Fig. 75 and Pl. 22.)

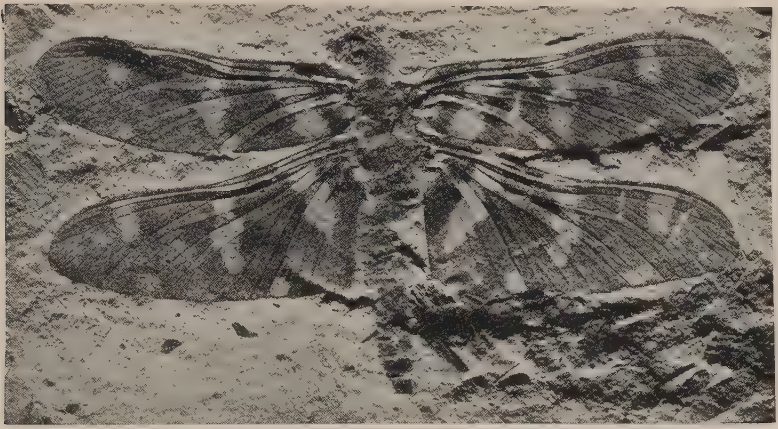


Fig. 83. — A primitive insect (*Dunbaria fasciipennis*) from the Early Permian of Kansas, preserving the color pattern. × 2.5. Peabody Museum, Yale University.

The discovery of these first four-legged vertebrates was of course a milestone in Historical Geology. The first recorded evidence of a Carboniferous land vertebrate came from our old friend, Sir William Logan, who found the imprint of a foot at Horton Bluff, Nova Scotia, in 1841, which was duly named *Hylopus logani* by that other great Canadian geologist, Sir William Dawson. The first skeletal remains on our side of the ocean also came from this region, but from Pennsylvanian beds, where they were found in 1853 by Lyell and Dawson, who came upon them, " incidentally and unexpectedly," in one of the fossil tree trunks in the Joggins coal beds; carried back to England in triumph, they were described by Sir Richard Owen, pioneer comparative anatomist and paleontologist, and fittingly named *Dendrerpeton acadianum*, the tree-reptile of Acadia. This skeletal find was, however, antedated by one reported in Germany in 1844 by a Dr. Gergens, and by Goldfuss' revelation in 1847 that *Archegosaurus*, regarded as a fish since 1777, was in reality an amphibian.

Even with this early start, the number of known Carboniferous amphibians is far from large, only 46 genera being recorded. Most of our American forms come from a few well known localities. The Joggins total is now 15 species. Heading the list in point of numbers are the coal beds at Linton, Ohio, which have yielded 51 species, but surpassing them in interest are the famous ironstone nodules that occur in Mazon Creek, Illinois. Besides rare amphibian remains, these nodules are rich in leaves and in marine shrimp-like animals and insects, specimens of which are widely scattered in the museums of the world. Collectors, patiently gathering these nodules out of the creek bed and cracking them open (the rate of amphibian yield is said to be 1 in 100,000

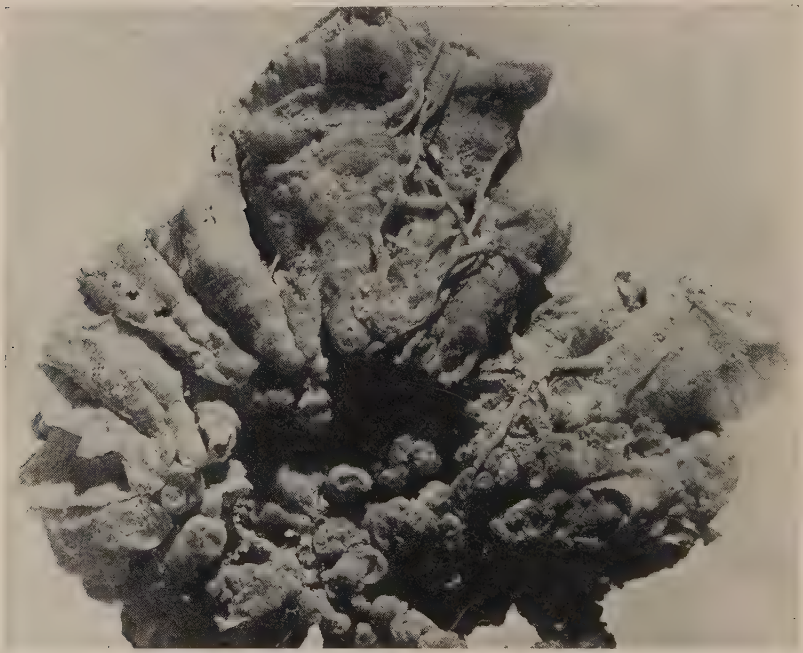


FIG. 84. — *Richthofenia.* Under side of a cluster of these remarkably specialized brachiopods, showing their coral-like growth and form. The individual at the top of the picture has the lid-like dorsal valve in place. In the center are shown many scars of attachment of different ventral valves. Middle Permian (Leonard), Glass Mountains, Texas. Photograph by R. E. King. Peabody Museum, Yale University.

nodules!) have brought to light an amphibian fauna of 10 species, one of which is illustrated in Fig. 85. These are the oldest known amphibian skeletons in North America. (R. L. Moodie.)

Somewhere in the course of Carboniferous time, the amphibians took the next upward step in vertebrate evolution, divorcing themselves entirely from their aquatic habits and becoming true land animals. The early members of the new type, the primitive *reptiles*, lived alongside of the stegocephalians in the Late Pennsylvanian, the two groups much resembling each other but distinguished by two important developments: (1) the eggs of reptiles are always far larger, with much more yolk, and are laid upon the dry land; (2) the young reptiles are born with lungs instead of gills, and thus are not obliged to begin life like tadpoles, *i.e.*, in the water. The reptiles also show a constant number of five digits on each foot, the standard type for the higher vertebrates. These first reptiles are known collectively as *cotylosaurs*, and form a generalized stock out of which may have evolved, directly or indirectly, the lizards, alligators, and dinosaurs.

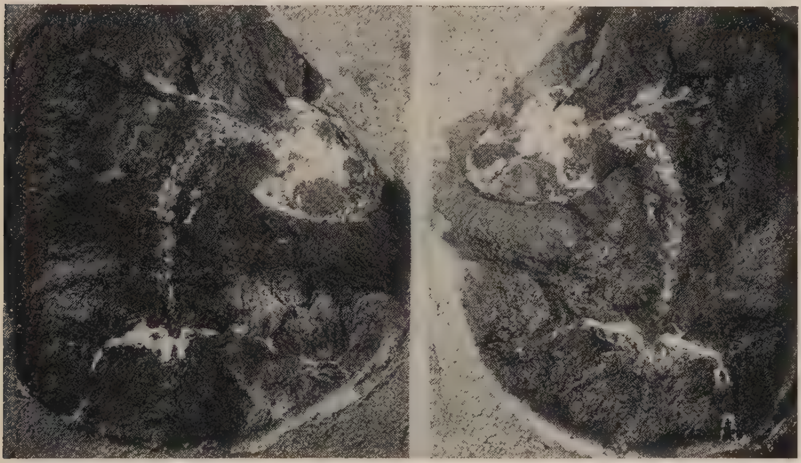


Fig. 85. — Two halves of a nodule from the Pennsylvanian at Mazon Creek, Illinois, showing the skeleton of one of the oldest known American amphibians, *Amphibamus grandiceps*, 2.5 inches long. Peabody Museum, Yale University.

The early reptiles, plump, sprawling sun-baskers, found themselves faced with a new problem as the ease of Pennsylvanian time gave way to the aridity and cold of the Permian. The growing scarcity of fresh water, and the cooling temperature, put a premium on activity. They responded by developing more alertness, longer limbs and hence more speed, and, in certain forms, fiercely carnivorous habits, apparent in

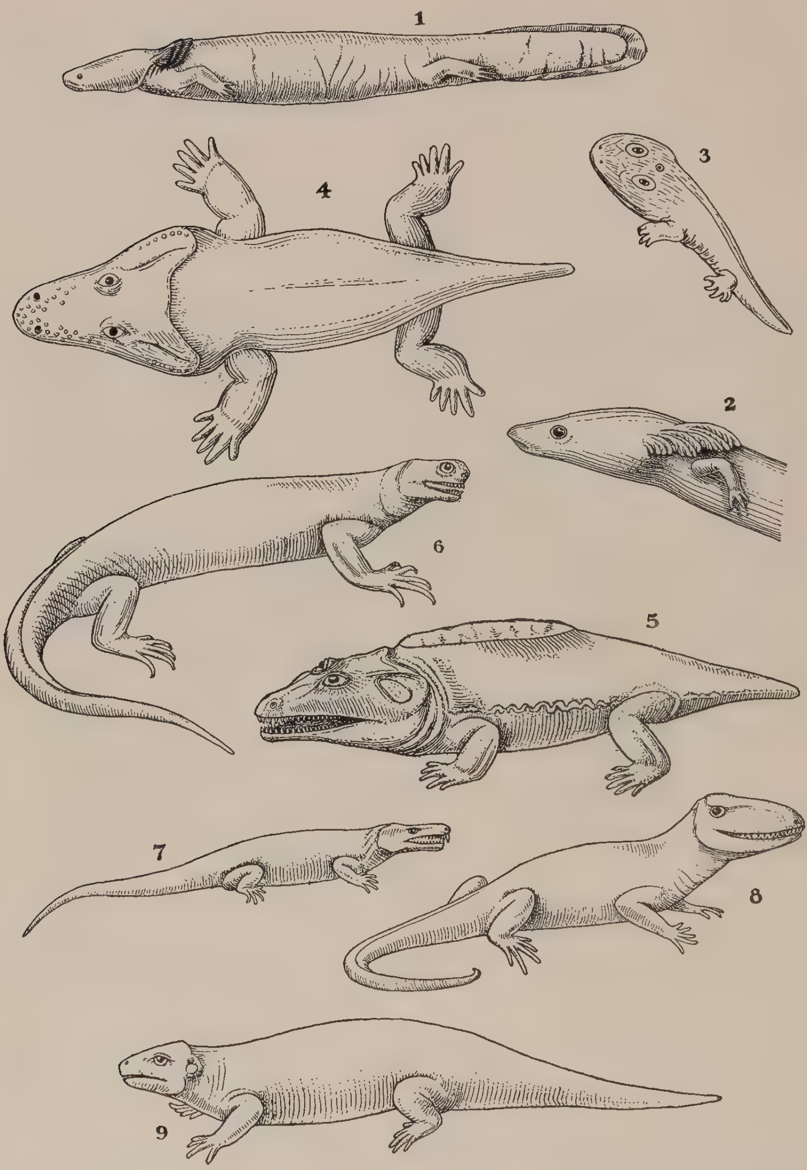


Plate 22. — Living (1, 2) and Permian amphibians (4, 5) and Permian reptiles (6–9).

Fig. 1, mud-puppy, *Necturus maculatus;* 2, salamander, *Siren lacertina;* 3, tadpole-like stegocephalian, *Branchiosaurus;* 4, stegocephalian, *Trematops milleri;* 5, *Cacops aspidephorus;* 6, *Casea broilii;* 7, *Limnoscelis paludis;* 8, *Ophiacodon mirus;* 9, *Diasparactus zenos.*

sharp recurved teeth and efficient claws. Aiding them also in their advance was the better food provided by *Gangamopteris* and other Permian plants, and as a result of these combined factors, by the end of the Permian they were present in great diversity all over the world. Their higher development is held by some authorities to be the most significant phase of the whole progress of evolution, for in the Late Permian we find forms foreshadowing the dinosaurs, birds, and mammals of later times. (Fig. 86, and Pl. 22.)

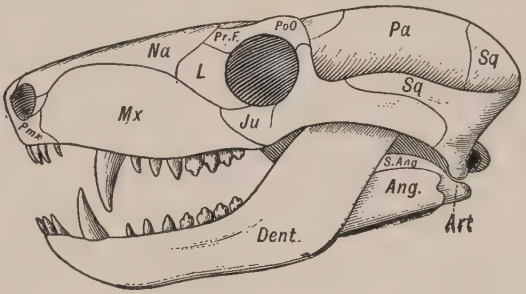


Fig. 86. — A theriodont reptile skull, about 4 inches long, from the Triassic of South Africa, showing primitive mammalian type of teeth. Similar ones occur in rocks of Permian age. After Broom.

Two of the regions that have the best records of these Permian reptiles are our own Southwest, where certain of the 80-odd known species of the earlier part of the period reached a length of 8 feet; and South Africa, which has in its Karroo system upward of 100 genera, one of which was 9 feet long and 5 feet high. It should be noted that the American development precedes the time of the ice age, whereas that in Africa follows it. Interesting among these land assemblages, as exceptions always are, is *Mesosaurus*, which forsook the land for an aquatic (marine?) home, appearing at about the same time both in Brazil and in South Africa.

CHAPTER XV

EARLY MESOZOIC TIME

The Mesozoic Era

We have now passed in review the greater part by far of the Earth's geologic history, and yet what is to follow is the most interesting part, because of the increasingly modern aspect of the life.

To the founders of Geology the Mesozoic rocks were known as the "Secondary" formations, situated above their Primary (Paleozoic and older eras) and beneath their Tertiary (Cenozoic). To them, the Mesozoic was, therefore, the middle or medieval time of the Earth's history, and they selected a name meaning medieval life to express that idea. It is now well known that the Mesozoic formations are far from holding the middle *time* of geologic history, but the *life* known to geologists is medieval in character and it is in this sense that the term is used.

Length of the Mesozoic. — On the basis of radioactive minerals we have seen that the Paleozoic era endured about 330 million years, and judged by the same kind of data the Mesozoic lasted about 110 million. Although this is but one-third the length of the Paleozoic, it is twice as long as the succeeding era, the Cenozoic.

Distribution of Mesozoic Formations. — In the introductory pages to the Paleozoic, attention was directed to the undisturbed Paleozoic formations in interior North America. The strata of the Mesozoic also lie undisturbed over the interior, but mainly between the Mississippi River and the Rocky Mountains, and from the Arctic Ocean far south into Mexico. Another region of the same formations, also in nearly horizontal attitude, is the Piedmont slope and the coastal plains west of the Atlantic Ocean from New Jersey south into Georgia, and thence widely through the states bordering the Gulf of Mexico into Texas, where they are continuous with those of the High Plains. In the Rocky Mountains and generally throughout the Cordillera, the Mesozoic beds are in folded or faulted relations due to later orogenies, and the same is true along the Pacific margin of the continent.

Divisions of the Mesozoic. — In North America, this era is naturally divisible into two almost equally long ages, Early and Late Mesozoic, separated by a time of grand diastrophism that affected the Pacific side of the continent. This significant mountain making registered its effects over a maximum width of something like 800 miles, and extended from Central America to Alaska. It is therefore truly of great import, and vastly more so than any of the disturbances at the close of other periods. It did not, however, bring on a "critical time" among the plants and animals, and hence does not have the organic significance attributed to the Permian and Late Cretaceous revolutions.

The Paleozoic era was, it will be remembered, divided into at least seven periods, but Medieval time is by common consent regarded as having only three, although on the basis of diastrophism it will eventually be divided into four. Early Mesozoic time includes two of these, Triassic and Jurassic, while the last half of the era is occupied by the Cretaceous.

From the organic standpoint, the Mesozoic was fitly named by Louis Agassiz the Age of Reptiles, for in the seas, in the air, and on the lands it was dominated by a very diverse and monstrous horde of reptiles. This fact is brought out strikingly when we say that during this era there lived not fewer than fourteen reptilian orders, among them brutes 60 to 80 feet long, with a weight of 30 tons or more, whereas to-day there are living but four orders, only three of which are widely dispersed, and none of which has representatives larger than the crocodiles or alligators or boa constrictors.

The mentality of these Mesozoic Reptilia was always of a low order, but better things are already indicated in the Early Jurassic, where we see the first primitive mammals, while the first birds appear in the Late Jurassic.

TRIASSIC GEOGRAPHY

(Plate 23)

In Germany where the Triassic system was first studied, these rocks comprise three thick formations, a grey limestone or dolomite lying between red beds. Because of this threefold character the system was named Triassic. This Germanic phase, however, begins and ends with continental formations and accordingly is not the normal marine sequence so necessary in a standard for stratigraphic correlation that is based on the record of the seas. By general consent, therefore, the six series or epochs of the Tyrolian Alps, the so-called Alpine phase, have become the standard for Triassic correlation, and in recognition of this fact the period is sometimes given Goodchild's name of Tyrolian.

The most striking aspect of North America in Triassic time was the emergent condition of the continent. Along the east side was the Appalachian highland, descending into the broad interior plains that had been so long beneath the sea. These plains continued west across what is now the high Cordillera, and apparently the only highlands in

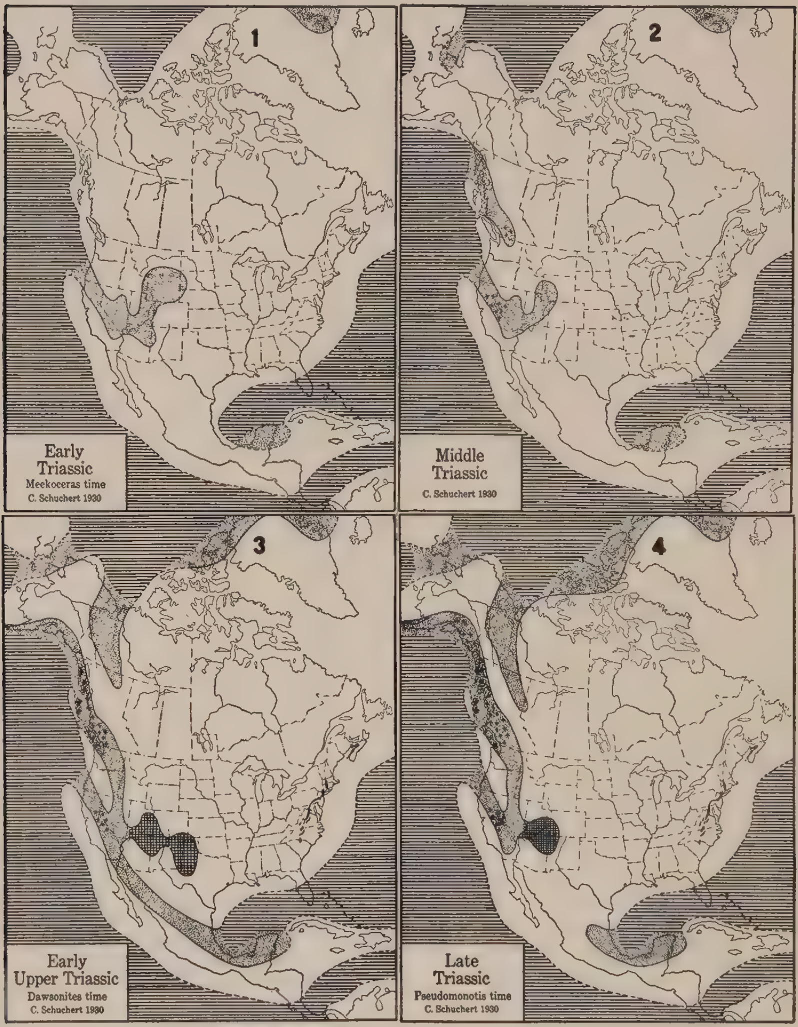


Plate 23. — Paleogeography of Triassic time.

Epeiric seas dotted; oceans ruled. Desert and semiarid deposits either cross-ruled or solid black (along Atlantic piedmont). Volcanic regions indicated by crosses.

Note the absence of the Appalachic geosyncline, the marine areas during Mesozoic time being in the Cordilleric and Mexican regions.

this area in Triassic time were those of the San Luis Obispo mountains of Colorado and New Mexico; there may have been others, but they are as yet unknown. The outer borderland along the Pacific was also a highland area (see Pl. 23). Because of the widely emergent and low condition of the continent, with highlands along the Pacific coast to shut out the moisture-laden winds, the desert climate of the Permian was continued throughout Triassic time, and the geologic record in the area of the southwestern states consists largely of variegated fresh-water deposits with scattering fossil plants and reptile bones. Early in the period, however, the Pacific flooded widely into the interior deserts of the Southwest. Otherwise the only recording was along the eastern side of the Appalachian Mountains, where a series of intermontane valleys from Nova Scotia south into Georgia were being filled by Upper Triassic fresh-water deposits.

Outside of the one Early Triassic invasion into the Southwest, the flooding by the oceans was restricted to the Pacific side and the Arctic. The more persistent floods lay in the Californic and British Columbic geosynclines, and from time to time, and especially during the Late Triassic, there were here many volcanic islands. In the marine deposits, which are usually very thick, there are vast amounts of ash and lavas, attesting the presence of volcanoes from California far into Alaska.

The Triassic of North America is therefore displayed under five main regional phases: (1) Atlantic border with intermontane continental deposits and land life only; (2) Arctic marine; (3) Great Basin, consisting of some normal marine deposits, much gypsum laid down in small, highly saline basins, but mainly of fresh-water and desert red-bed formations; and (4) normal marine deposits of the Pacific geosynclines, with volcanic beds. The last-named troughs were also in direct communication with (5) the Mexican geosyncline. It is these regional records that we will now examine.

Atlantic Border. — At the outset of the Mesozoic, the eastern side of North America was still sufficiently under the influence of the Permian mountain making to be all highland; in fact, as we have learned in earlier chapters, even though the Appalachians were subsequently worn down greatly from their Permian grandeur, the Appalachian geosyncline was gone forever and the seas never again entered that region. Beginning with about Middle Triassic time, there was a further uplift of the land to the east of the Appalachian foldings of Permian time, all the way from Nova Scotia to the Carolinas. In this highland tract there was faulting along the eastern and western sides, letting down narrow troughs that sank in places 3 or more miles (see Fig. 87).

Such narrow subsiding areas, it will be remembered from Part I, are called graben. This faulting continued after Triassic times. The major fault-lines of these troughs can be traced along the eastern side of the Connecticut Valley (here the displacement or drop was about 2 miles), and others of equal importance are known in the western parts of the Triassic areas of Maryland, New Jersey, and Pennsylvania, and in Nova Scotia as well. The constantly rejuvenated lateral highlands were subjected to quick erosion, and into the sinking valleys alongside, the seasonal rivers brought down vast amounts of sediment, the present Triassic formations. These rapidly accumulating continental deposits are known as the *Newark series*, from the city of that name in northern New Jersey. They are conglomerates, sandstones, siltstones, and shales, abundantly mud-cracked, rain-pitted, and rippled — in other words, the material eroded from an eastern highland of crystalline rocks and from the Appalachian Mountains on the west, deposited in a semiarid climate with hot summers. In the Connecticut Valley there are probably 10,000 to 13,000 feet of these intermontane deposits (Fig. 88), and in New Jersey and southeast Pennsylvania the maximum thickness is said to be over 20,000 feet. Southward they thin rapidly, showing about 2500 feet to the west of Richmond, Virginia, and about 3000 feet in North Carolina (see Pl. 23, Map 3). The prevailingly red color of these Triassic rocks and of the soil derived from them is a striking feature of the landscape in the regions where they occur.

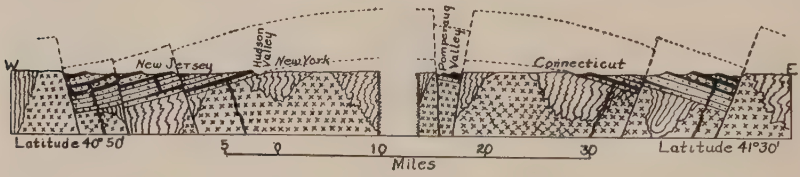


Fig. 87. — Idealized representation of the Triassic rocks in Connecticut and New Jersey. The inclined sedimentary strata (indicated by dots) rest unconformably on deformed and metamorphosed ancient formations (granite shown by crosses and sedimentary strata by wavy lines). Basalt flows, with related sills and dikes of dolerite, are shown in black. The whole area is now block faulted and dropped differentially. two miles or more at the eastern and western ends and far less in the center, causing the medial region to be arched. It is not, however, certain that Triassic rocks extended entirely across the arch, as suggested in the figure. Western Connecticut, about 35 miles in width, is omitted from the diagram; to show the full extent of the arch the two parts of the section would have to be pulled apart to the ends of the scale of miles. Drawing by C. R. Longwell.

In the Upper Triassic areas of Virginia and North Carolina there is much black shale with decidedly local bituminous or humic coals, and rarely a zone of black-band iron-ore. Plants are common in the coal-bearing strata of Virginia (40 kinds). These dark deposits with coal swamps show that the climate was not always and everywhere semiarid, but that locally there were humid conditions, with swamps.

Nowhere have the Newark strata yielded a single marine fossil, all of the recovered organisms being those of the land (plants and vertebrates) and of fresh waters (fishes, bivalves). Actual remains of plants and animals are always rare in red desert deposits, and the common organic evidence here, therefore, consists of footprints made chiefly by dinosaurs (see Fig. 95).

In all of the Newark areas from Nova Scotia to North Carolina are found igneous rocks that in the lower strata occur as intruded sheets and dikes of trap (dolerite), and higher up are extruded sheets of basaltic lavas in thicknesses up to 900 feet (Fig. 88). These are seen to best advantage along the Hudson River in New Jersey, where they make the well known Palisades, whose vertical walls of columnar rock exhibit the edge of a great intruded sheet of dolerite, exposed by the subsequent erosion of the softer rocks formerly surrounding it. The molten material welled up repeatedly toward the close of Newark time through fissures situated in the deepest parts of the subsiding areas and near the great faults. (Fig. 89.)

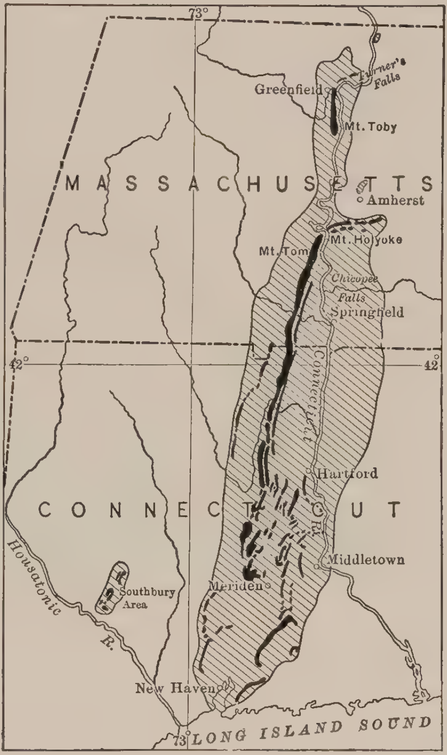


Fig. 88. — Triassic continental deposits (ruled areas) and igneous rocks (solid black) of the Connecticut Valley. U. S. Geol. Surv.

Palisade Disturbance. — At the close of the deposition of the Newark series, crustal deformation again set in, apparently on a considerable scale, from Nova Scotia to South Carolina, and this makes a natural boundary between the Triassic and Cretaceous (the Jurassic being absent). Everywhere this new area of deformation lay east of the Appalachian foldings but paralleled them closely. The Appalachians had been folded and overthrust to the west, but now the surface was elevated and broken by normal faults of varying magnitude, and the strata in each basin were tilted into a series of monoclinal blocks, all dipping in the same direction. As a result there were formed chains of block mountains similar to those in the Great Basin province to-day. These so-called Palisade mountains comprised eight to ten independent ranges, occurring at intervals over an extent of 1000 miles. The Connecticut River range was 120 miles long and the Palisade range, extending from southern New York into Virginia, had a length three times as great. They were all peneplaned during Cretaceous time. (Fig. 90.)

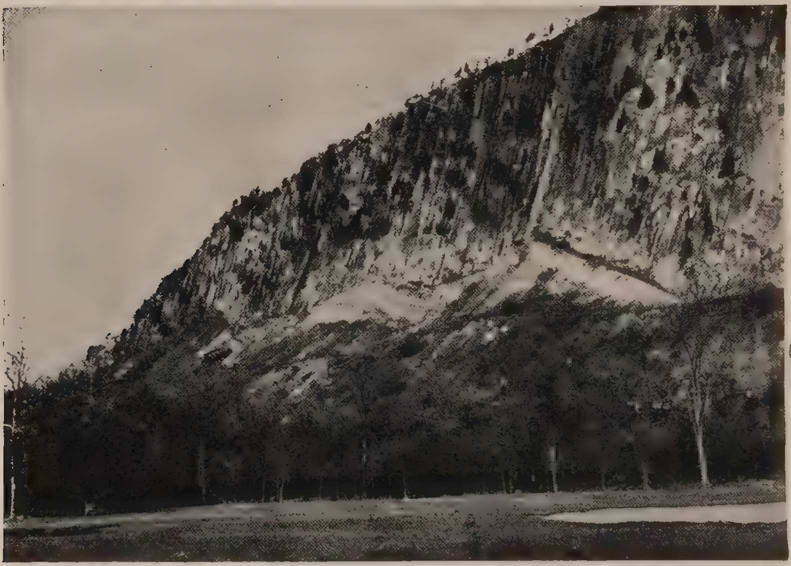


Fig. 89. — West Rock, New Haven, Conn. A dolerite sill, intruded into Triassic rocks that are now all eroded away except at the base, where the red Triassic sandstones can be seen dipping eastward.

Great Basin. — In the area of the present Great Basin — the region between the Sierra Nevada and the Wasatch Mountains of Utah (*i.e.*, Utah, southeastern Idaho, Nevada, southeastern California, and Arizona) — there was in earliest Triassic time a very wide flooding from the Pacific. From the abundance in its deposits of the ammonite *Meekoceras* (Pl. 26, Figs. 11, 12), this is often called the Meekoceras sea (Pl. 23, Map 1). In Idaho the sea remained throughout Early Triassic time, long enough to deposit 5000 feet of shales, calcareous beds, and sandstones. Wyoming also has some thousands of feet of red beds of Lower and Middle Triassic (Popo Agie) time, mainly fine-grained sandstones and siltstones with widespread beds of gypsum that in places attain a thickness of 160 feet. These are, however, wholly devoid of normal marine faunas, and their scattering bones of reptiles and thick zones of gypsum give the impression that they were deposited in a vast series of interlocking shallow saline basins under a semiarid climate.

Further to the south, the Early Triassic marine conditions evidently alternated with those of shallow basins or lagoons, as recorded in the Moenkopi formation of southeastern Nevada and northern Arizona, which starts with normal marine limestone at the base and runs up into cross-bedded and ripple-marked sandstones, prevailingly red in color and accompanied by much bedded gypsum.

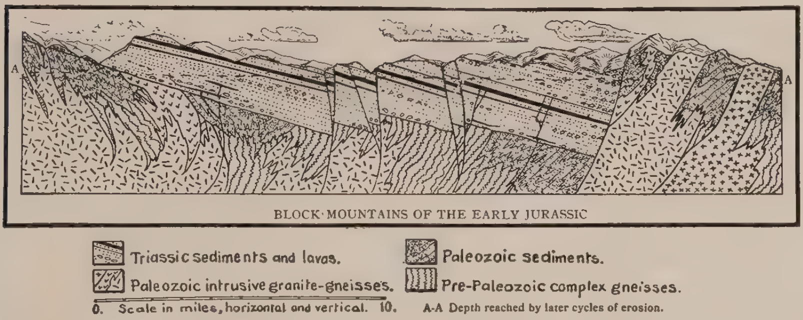

A
A
BLOCK·MOUNTAINS OF THE EARLY JURASSIC
Triassic sediments and lavas.
Paleozoic sediments.
Paleozoic intrusive granite-gneisses.
Pre-Paleozoic complex gneisses.
0. Scale in miles, horizontal and vertical. 10.
A-A Depth reached by later cycles of erosion.

FIG. 90. — Sectional view of the block mountains of Early Jurassic time in Connecticut. After Barrell.

In Late Triassic time, great parts of Arizona, Utah, New Mexico, and western Texas (Pl. 23, Map 4) became a semiarid land of red-bed formations. These Late Triassic records are all of fresh-water, wind, and desert making; they have scattering plants (mainly leaves of cycads and stems of equisetum), and bones of reptiles, best preserved in the Chinle formation of Arizona. The reptiles belong to the group known as phytosaurs (Fig. 94), animals related to the gavials and crocodiles of the present, and living very much as these do now. Associated with them were lung-fishes. Their homes were in great, low-lying flood plains, traversed by slow-moving streams subject to occasional overflows and freshets, and interspersed with swamp areas and shallow lakes, with scattered stands of conifers on higher ground. In the vicinity were explosive volcanoes, and the ash falls from them may at times have locally killed the reptiles. (C. L. Camp 1930.)

The lower Chinle formation is one of the most beautifully colored of all deposits, its cliff faces banded with purple, pink, and gray, its softer marls and shales making a " painted landscape " with patches and bands of yellow, ash-gray, drab, lavendar, rose, pink, slate, maroon, sienna, lilac, cream, and various shades of red and brown (Gregory). This great variety of colors is in part due to the presence of different kinds of volcanic ash (bentonite is reported by Camp), the colors being due to chemical changes that the minerals have undergone in the ash beds and the other deposits. It is also in this formation that occur the silicified logs of the petrified forests elsewhere described in this chapter.

Arctic Sea. — In Late Triassic time the Arctic spread widely over the archipelago to the north of North America and over northwestern Greenland, and flooded down the Mackenzie Valley into northern British Columbia, carrying a fauna characterized by the ammonite *Dawsonites* (Pl. 23, Map 3). This marks the reappearance of the Cordilleric geosyncline, which has been absent here during the earlier epochs of the Triassic but which will become more and more prominent into Late Cretaceous time; to the west of this geosyncline lay the Central Cordilleran geanticline, the rising arch and the subsiding seaway appearing together. The history of the arch will be discussed in Chapter XVII.

Pacific Geosynclines. — Except for the Arctic invasion mentioned in the preceding paragraph, marine recording in the Late Triassic, so far as the United States and Canada are concerned, is almost wholly restricted to the narrow geosynclines along the western side. Nevertheless it is a most interesting development and compares favorably with that of the rest of the world. Beginning in the northwest is the *British Columbic sea* (Pl. 23, Map 4), which appeared in Middle Triassic time and became widespread in the later part of the period, when it extended from the Aleutian Peninsula south into the state of Nevada. In southern British Columbia the deposits of this seaway attained 13,000 feet in thickness (Nicola formation), nine-tenths of which is ash and lavas, coming mainly from submarine volcanoes.

Farther south, where now are the Sierra Nevada Mountains, lay the *Californic sea,* confluent northward with that of the British Columbic trough (Pl. 23, Map 4). In the former area the Triassic record compares favorably with those of Europe and Asia. The deposits are usually calcareous and about 4000 feet thick. In early Upper Triassic time the geosyncline continued southeast through the state of Sonora into the Mexican trough that opened out into the Gulf of Mexico.

It is interesting to note here that these Pacific geosynclines receive at times marked invertebrate migrations from the western Mediterranean by way of the Mexican trough, as well as Oriental ones that spread along the coast of Asia, Alaska, and Canada; these alternated with migrations of cool-water species that came from Siberia on the west or from North Greenland on the east. Such migrations from warmer or cooler waters were made possible by the closing or opening of the Behring Sea portal through the Siberian-Alaskan land-bridge. (See Fig. 127.)

JURASSIC GEOGRAPHY

(Plate 24)

In Europe, over the Triassic lies the widely distributed and usually but little disturbed Jurassic. The high lands that were made during the close of the Paleozoic had now vanished, and extensive epeiric seas, with a life that was astonishingly rich and varied, gradually spread over the continent. Probably as many kinds of fossils are known from Jurassic rocks alone as from all the other Mesozoic strata combined, and because of this prevalence of organic remains, these formations have been the training ground for many European stratigraphers and paleontologists. In England, these deposits furnished fossils to "Strata" Smith, who was the first to discern in them a value as aids in determining the age of the containing rocks. In fact, it is from the Jurassic deposits of England, Germany, and France that the principles upon which Stratigraphic Geology depends have been worked out, and yet the period takes its name from the Jura Mountains on the boundary between Switzerland and France.

From the studies of the abundant Jurassic marine faunas, and chiefly the ammonites, came also the first clear ideas of climatic zones in Geology and of paleogeographic maps (Neumayr-Marcou).

North America, however, stands in strong contrast to the European Jurassic development, for our record is one of erosion and peneplanation over three-fourths of the continent. On an earlier page we saw that the Triassic along the *Atlantic border* closed with the Palisade Disturbance, a movement that resulted in the making of block mountains, probably somewhat lower than the present Sierra Nevada. Accordingly, Jurassic time here opened with active erosion, and whatever continental deposits were formed at the time were swept into the Atlantic Ocean. This erosion cycle brought about the final transformation from the previous topographic expression of high Appalachian and lower Palisade mountains to a nearly base-leveled land, thus preparing the way for the next overlap of the Atlantic Ocean, late in Cretaceous time. Only in Mexico and in the western portion of the continent did the Jurassic oceans invade the land. Hence probably fewer than 600 kinds of Jurassic fossils have been described from North America, while Europe has yielded nearly 15,000 forms.

Triassic time closed along the *Pacific border* with a slight emergence of short duration, but early in the Jurassic the Pacific Ocean began more

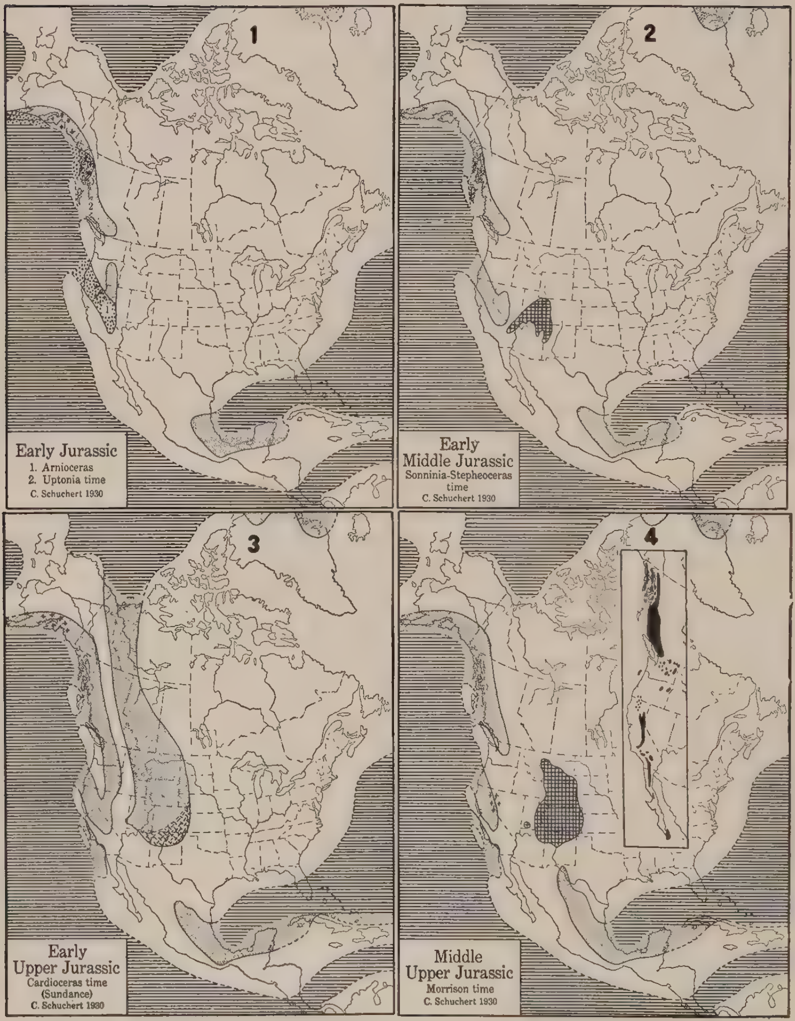


PLATE 24. — Paleogeography of Jurassic time.

Epeiric seas dotted; oceans ruled. Fresh-water deposits cross-ruled; red beds and gypsum marked by diagonal dashes. Volcanic regions indicated by crosses. See Plate 25 for latest Jurassic physiography.

Note the Central Cordilleran geanticline separating the seas of the Pacific and Cordilleric (Rocky Mountain) geosynclines (Map 3). The inset on Map 4 shows the extent of the batholiths intruded during the late Jurassic and the early Cretaceous.

and more to overlap the Aleutian Peninsula and Alaska and to fill the British Columbic geosyncline south across the Queen Charlotte and Vancouver islands into Washington, attaining a maximum of spread in Late Jurassic time. In Alaska there are about 10,000 feet of coarse deposits, along with tuffs and andesitic lava flows, supplied in part by submarine volcanoes, as in Triassic time (see Pl. 24). Along the whole Pacific side of the continent, in fact, intermittent volcanic activity had been playing a great rôle since Middle Paleozoic time, and more than one half of the Triassic and Jurassic rocks of the Pacific geosynclines are of volcanic origin.

In the Californic geosyncline, the sea reappeared as early and endured about as long as the one in the northern trough, depositing in the states of California, Oregon, and Nevada about 4000 feet of muds and sands with but little limestone. The record is the most complete Jurassic one in the United States but the fossils appear to be scarce and badly deformed. In California these rocks yielded the much-sought-after placer gold that started the nation westward in the early forties (see page 204).

The *arctic floods* did not at any time during the Jurassic submerge North Greenland or the arctic archipelago, but toward the close of the Middle Jurassic a cool-water sea began to spread down the Mackenzie Valley into Utah and Colorado, in other words, through the same geosyncline that had been invaded by the Dawsonites sea of the Early Triassic; at neither time had it connection with the Pacific geosynclines (see Pl. 24, Map 3). This arctic flood is known as the *Sundance sea*, after the Sundance beds that it left behind in Wyoming. Its deposits — sandy clays, shaly marls, impure limestones and sandstones — are much cross-bedded, and this fact, along with the presence of oysters locally, indicates that the sea was a shallow one. Its small fauna, moreover, made up almost entirely of molluscs, shows that the waters did not belong to the open sea, but were those rather of a large inland bay. Although of wide extent, the Sundance sea was of short duration.

To the west of the Sundance sea was, again, the Central Cordilleran geanticline that furnished most of the sediment for the seas in the Cordilleric trough.

Early in Jurassic time the *Gulf of Mexico* again spread northwestward into the Mexican geosyncline, extending farther and farther northward until in the latter part of the period it attained Texas. In this trough the sediments are in the main limestones and calcareous shales abounding in ammonites showing European affinities. When this flood was greatest, western Cuba for the first time went beneath the sea, a circumstance prophetic of the general submergence of the Greater Antilles during Cretaceous time.

Continental Deposits. — Overlying the marine Jurassic throughout the Great Plains country, from Montana south into New Mexico, occur variegated green and red marls and shales with irregularly distributed beds of sandstone. These are the Morrison continental deposits (Pl. 24, Map 4), so called because they were first studied at Morrison, near Denver, Colorado. They yield fresh-water bivalves, snail shells, and some turtles, along with land plants, but the most striking fossils are the dinosaurs and small archaic mammals. These deposits are thought to have been laid down over a comparatively low and level plain near sea-level, the abandoned bottom of the Sundance sea, then occupied by lakes and swamps connected by an interlacing system of river channels, in which most of the gigantic dinosaurs lived. The topography and climatic conditions of that time were probably much like those of the lower reaches of the Amazon to-day.

The desert conditions prevalent in the southwestern states in Late Triassic time continued into the Jurassic, resulting in formations that are likewise rich in color and in erosional form. These pages of American history are revealed strikingly to-day in Zion Canyon of southeast Utah, "the rainbow of the desert," carved out by the Rio Virgin, one of the tributaries of the Colorado (see Frontispiece). Here the walls blaze with color: at the base, the greens and grays and yellows of the Triassic "Belted shales"; above, in succession, a hundred feet of brown conglomerate, 350 feet of Painted Desert beds (Chinle), red and mauve and purple; then 2000 feet of red Jurassic "Vermilion Cliff" sandstone, surmounted by another thousand feet of glistening white ("White Cliff"), forming the main body of color; in places above these, 600 feet of drab shales and chocolate limestones mingled with crimsons that streak down across the white beneath. And, chiseled out of these varicolored rocks by the rains and winds of millions of years, the superb Temples of the Virgin, 5000 feet from base to top, with "the mass and proportions, the dignity and grandeur, of a cathedral" (Yard). "No wonder," says C. E. Dutton, who described the canyon in 1882, "no wonder that the fierce Mormon zealot who named it was reminded of the Great Zion on which his fervid thoughts were bent, of 'houses not built with hands, eternal in the heavens'."

The above account of course deals with the Jurassic rocks as they look to-day. In Jurassic time, however, these strata were merely the wind-blown and water-borne materials brought from adjacent highlands into a desert. Finally, late in the period the Sundance sea invaded the area from the north and covered these older desert deposits in Utah, Colorado, and New Mexico (see Pl. 24, Map 3).

The Jurassic seems to have been a time of widespread coal making,

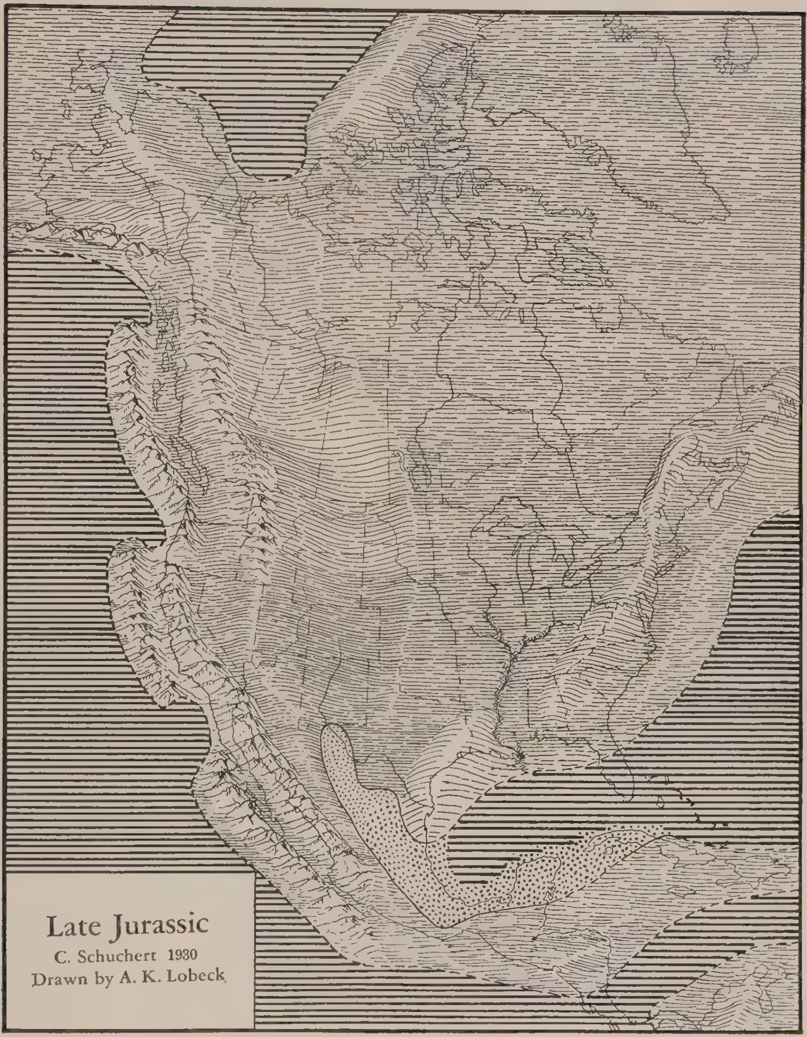


Plate 25. — Late Jurassic paleophysiography.

The probable geography of late Jurassic time, when the Sierra Nevada and other mountains of the Pacific system were rising (see p. 204). The Central Cordilleran ridge to the east of these mountains was rising, but is here drawn too high, while the Cordilleric or Coloradic geosyncline is shown as too deep. Note that the Appalachians are greatly reduced, and that the Mississippi drainage may have begun this early.

since coals of this age are known in Mexico, California, Greenland, Spitzbergen, Europe, Siberia, India, China, Australia, and South Africa.

Nevadian Revolution. — Toward the close of the Jurassic, the Pacific System of mountains (Sierra Nevada, Coast Ranges of California and British Columbia, Humboldt, Cascade, and Klamath mountains; see Fig. 117) was elevated out of the Californic and British Columbic geosynclines. This very decided crustal movement is called the Nevadian Revolution, although it is of less import than the other revolutions. With the rise of the mountains to the east and west, there came into existence between them the Great Valley of California, a narrow but long geosyncline that has persisted into the present. Although the mountains mentioned appear to have been the regions of most active deformation, the effects of this orogeny can be traced from Central America into northwestern Alaska. (See Pl. 25.)

While the Pacific border of North America was being folded, the Earth-shell was also invaded by deep-seated igneous rocks (granodiorite) on a magnificent scale. At the surface there were immense outpourings of lava, which are conspicuous in the present Sierra Nevada. Magmas in great volume were intruded, forming the great chain of batholiths now exposed by erosion along the Pacific border from Lower California to the Alaskan Peninsula (see Pl. 24, Map 4). The batholith of the Sierra Nevada is 400 miles long and has a maximum width of 80 miles, while on the International Boundary there are twelve batholiths that have a combined width of 350 miles. The Coast Range batholith of British Columbia, probably the greatest single intrusive mass known, runs unbroken for 1100 miles into the southern Yukon. These intrusions can be compared only with the Laurentian and Algoman ones on the Canadian Shield; all other post-Proterozoic ones fade into insignificance beside them. It is thought that although the intrusions may have started in Middle Jurassic time, the main injections took place at the close of the period, extending into Lower Cretaceous time, and that less significant upwellings went on even to the close of the Mesozoic era.

The gold-bearing veins of quartz in the rocks of the Sierra Nevada formed as a result of the igneous invasions. The opened spaces and fissures became filled with silica (quartz) deposited by the heated solutions coming from the batholiths below, which also brought with them the ores now found in the veins. The erosion of these veins has furnished the gold found in the sand of rivers flowing out of the mountains (see page 48 of Part I). The silver and copper ores in the Coast Ranges of British Columbia likewise date from this time.

Eruptions of volcanic rocks on a tremendous scale occurred during the Jurassic in South Africa and eastern South America.

LIFE OF EARLY MESOZOIC TIME

Résumé of Climatic Changes. — In earlier chapters, we traced the broader features of the marine life of the Paleozoic era, and saw as well how the lands become clothed with vegetation in preparation for the few stocks of animals that from time to time ventured out of Neptune's realm. In the seas the most striking change came with the Devonian, when the fishes battled with the shell-encumbered cephalopods, and won. At the same time, or possibly earlier, the river fishes of semiarid areas periodically found their water homes drying away for a time, making it necessary for them, if they were to live on and perpetuate their kind, to find means of hibernating until the water returned. Living in overcrowded water holes, or hibernating, some of them learned to develop lungs, and so was started the invasion by the vertebrated animals over the plant-covered lands, and as race after race became better adapted to land life, they spread farther and farther away from water. This evolution took place while the Earth's climate was in most places warm and mild to tropical.

Already in the Late Pennsylvanian there is evidence of coming great climatic changes. The cause for these is the rising of mountain chains in many continents (see page 180), and by Middle Permian times the lands in the northern hemisphere are mostly deserts. On the other hand, most of the continents in the southern hemisphere are rising into high plateaus and getting colder, and accordingly toward the latter part of Middle Permian time much of South Africa, Australia, South America, and peninsular India is mantled by continental ice-sheets. In consequence of so much high land with cool and dry climates, which continue through most of Triassic time, the living conditions are critical for the life of the lands and as a result we see both animals and plants undergoing great changes.

Early Mesozoic Transition Floras. — Somewhere to the south of the equator, and seemingly in Antarctica, there arose in Permian time, as we have seen, a new but sparse flora, consisting mainly of fernlike seed-plants, ferns, and cordaites; as the ice-sheets spread, this flora, characterized by the genus *Gangamopteris*, travelled northward, taking possession of all the lands, and by the beginning of Late Permian time had attained the northern hemisphere. What was left of the older native flora, along with these newer and hardy plants that were reared under trying climates, then began to dominate the lands of medieval times.

The older Mesozoic floras (often spoken of as the gymnosperm or naked-seed floras) were fairly uniform in character from Late Triassic time into the Early Cretaceous. They were made up in the main of conifer forests (araucarias, pines, cypresses, yews, " big trees " or sequoias), along with maidenhair trees and Cycadophytes (page 43). Of these medieval plants, it is the cycads that interest us here most, since among them were the greatest variety of forms, so that the Early Mesozoic is often called the Age of Cycads. These early cycads (cycadeoids) looked like the modern ones, but were in reality nearer the angiosperms, since they had genuine flowers which in some species were very large and apparently very showy affairs; they are most closely related to the living magnolias and tulip trees (Fig. 91). In their general plan the flowers were like those of the true flowering plants, developing a fruit that enclosed the seeds. These cycadeoid flowers may have attracted the insects of the time to aid in their cross-fertilization, starting thus early the interdependence of plants and insects so highly developed in the angiosperms. The cycadeoids have, in fact, been called proangiosperms. In Early Mesozoic time they rose into preëminence among plants, but in the later half of the era they were superseded by their descendants, the true angiosperms.

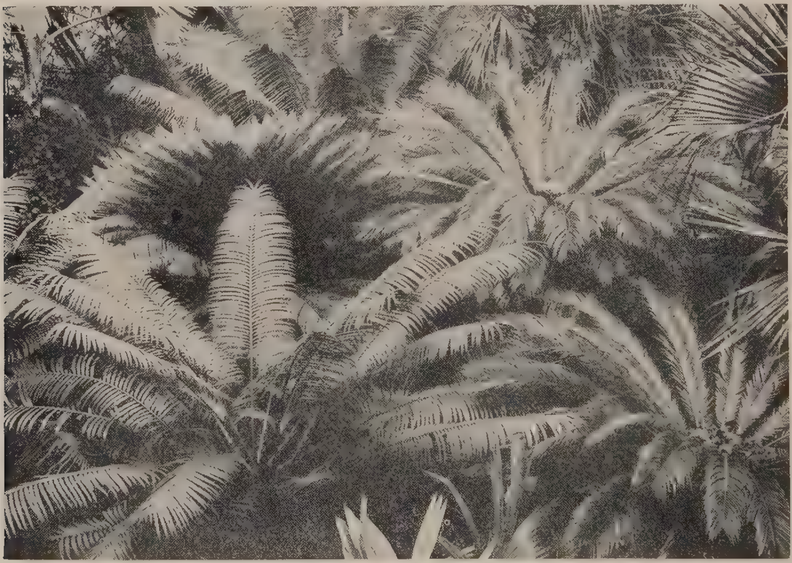


FIG. 91. — Living cycads in the New York Botanical Garden in 1908. Plants of this kind were common in Triassic and Jurassic times.

The most remarkable American locality for cycads is in the Black Hills of South Dakota, where 320 acres have been set aside as Fossil

Cycad National Monument. From this small area were gathered in the 1890's over 1000 cycad trunks, the largest one weighing about 800 pounds; most of these are now in the Yale and National museums.

In the older medieval floras there was also a great variety of ferns, but nearly all were of families different from those of the present day (Fig. 92). Horsetails or rushes were common and much like living ones, but all of the calamites were gone. On the whole, however, the cycadeoids were the most interesting part of the Mesozoic floras, and it is thought that two out of every five land plants were then of this stock (Wieland).

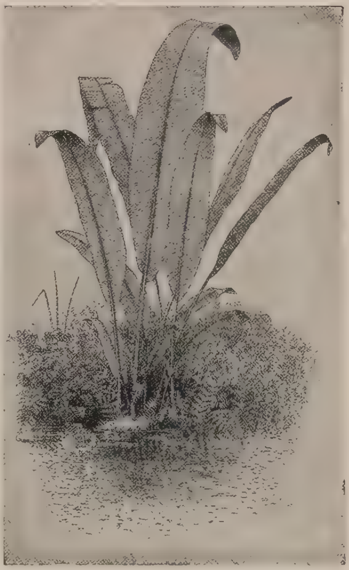


FIG. 92. — Giant broad-leaved Triassic fern, *Macrotæniopteris magnifolia.* U. S. Geol. Surv.

An astonishing number of conifers are to-day to be seen in the Petrified Forest National Monument of central Arizona, where agatized logs of Triassic age range up to 125 feet in length and have diameters as large as 7 feet. The alkaline waters of a desert delta soaked through the sands in which the trees were buried, after being brought by floods into shallow lagoons, and replaced the wood, molecule by molecule, with silica, in such a way as to preserve the minutest cellular structure; iron and manganese oxides, accompanying the silica in small amounts, stained the trees rich reds, yellows, and purples.

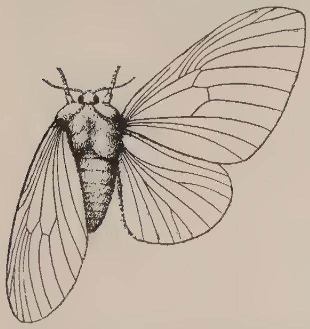


FIG. 93. — An Upper Jurassic butterfly (*Limacodites mesozoicus*), as restored by Handlirsch. From *Geschichte der Entomologie,* 1922.

Insects. — Judging from the insects of Triassic times, those of the later Permian must have introduced complete "metamorphosis" (a transformation, as maggot to fly, or caterpillar to butterfly) and resting stages, as a result of the winters and droughts. In the Jurassic, about 1000 species of insects are known, as against fewer than 50 in the Triassic. True butterflies (Fig. 93) and flies were rare in the Lower Jurassic, but caddis-flies, scorpion-flies, dragon-flies, and beetles were abundant. Other kinds of insects known from the Jurassic are the cicadas, grasshoppers, locusts, cockroaches, and termites. The social ants were certainly present in the Early Jurassic, arising out of primitive wasps of the kind that now live in deserts or hot sandy places.

Land Reptiles. — On the lands, the reptiles of Triassic time evolved into a great variety of forms. Sprawling, crocodile-like ones (*Rutiodon*, Fig. 94) and more active forms (*Stegomus*, *Stegomosuchus*) were common in the East; and similar types (phytosaurs) are better known in the Great Basin area and in Wyoming. Lords of the lands, however, were the dinosaurs, to be described in the next chapter. Making their entrance on the scene in the Late Triassic in the Connecticut Valley and elsewhere, they were already present in great variety and great size; in fact, some, known from their footprints only (Fig. 95), must have been as large as elephants. Best known is the carnivore *Anchisaurus*, which roamed the Connecticut Valley in Late Triassic time.

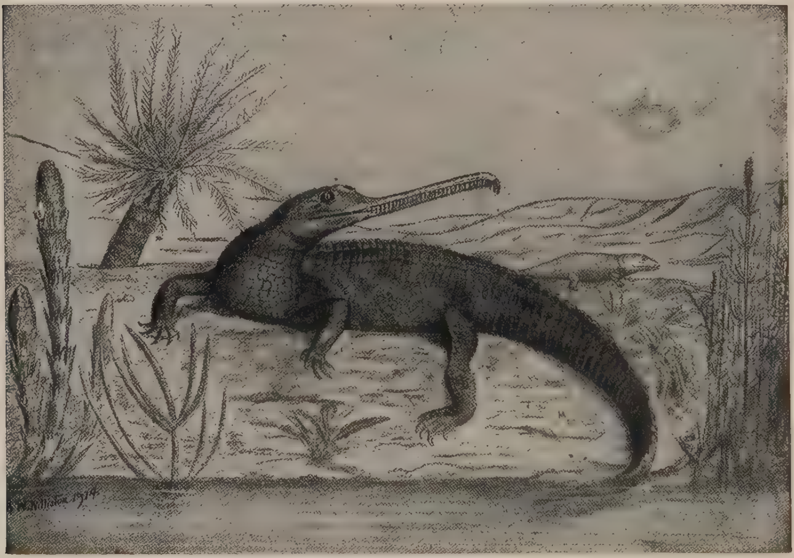


Fig. 94. — A Triassic phytosaur, *Rutiodon*. The plants are rushes and cycads. After Williston, from his *Water Reptiles*.

The Jurassic reptiles attained a more diversified development than those of the Triassic. True lizards appeared here, and the turtles were abundant and world-wide in distribution. One of the most remarkable groups of Jurassic carnivorous reptiles was that of the flying dragons, which are also described in the next chapter. The dinosaurs probably attained their zenith of differentiation in the Late Jurassic and then continued in fullness of development into the Cretaceous. The most characteristic of all were the Sauropoda, and other striking large forms occurred among the carnivores and armored types.

Marine Reptiles. — Although the reptiles were firmly established on the lands in Permian times, we saw at least one stock (*Mesosaurus*) going back to the waters of this period in South America and South Africa. In the Triassic, however, reptilian stocks took freely to the seas and oceans, where there is always much food easily to be had. Their going to sea may also have been stimulated by the prevalent desert conditions of Permian and Triassic lands. Dolphin-like reptiles, the ichthyosaurs, were abundant in the later Triassic, and long-necked, turtle-like plesiosaurs also had their start at this time. Here again we see the wonderful extent to which organisms can adapt themselves, for limbs have been changed from walking legs to swimming paddles, and the egg-laying method of rearing the young has been altered to that in which the young are born alive.

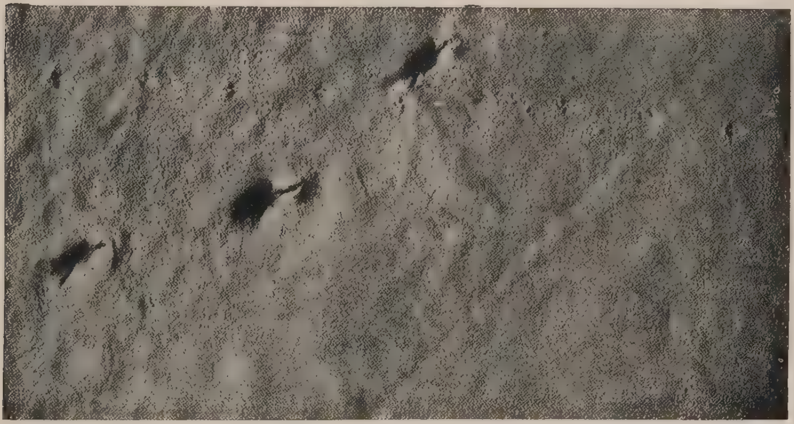


FIG. 95. — Slab of Triassic sandstone, 6 × 3.5 feet, pitted by rain. A large dinosaur (*Steropoides diversus*) walked over the muddy ground before the shower, and a much smaller one (*Argoides minimus*) afterward. Peabody Museum, Yale University.

The ichthyosaurs, though not so well represented in the Jurassic of this country as in Europe, are very well known to us because of their fortunate preserval in Germany and England in shales that are easily cleaned away from the bones, so as sometimes to show even the outline of the fleshy body. The earlier species moved about largely by the use of the four modified limbs, but the tail grew increasingly powerful until it came to be the almost exclusive means of propulsion (Fig. 96).

The plesiosaurs, on the other hand, were world-wide in their distribution. Carnivorous like the ichthyosaurs, the typical genus had a very small head, set at the end of a long snaky neck that was marked off distinctly from a boxlike body. These strange creatures reached their culmination in the Cretaceous seas. (Fig. 114.)

Birds. — Birds appear for the first time in the Late Jurassic, and represent one of the most remarkable advances that the life of this period has to show. These and other fossil birds are discussed in the next chapter.

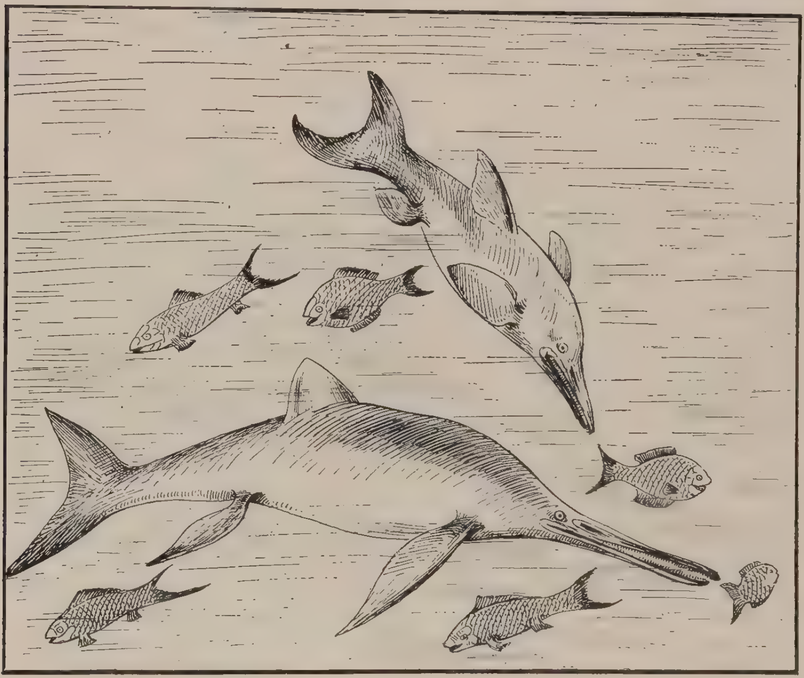


Fig. 96. — Restorations of Early Jurassic fish-lizards feeding on ganoid fishes. The long-snouted type (*Ichthyosaurus longirostris*) and the short-headed one (*I. quadriscissus*) are both found in Germany. More primitive ichthyosaurs occur in the Middle and Late Triassic of Nevada and California. From E. Hennig's Guide to the University of Tübingen Museum.

Mammals. — No mammals are known to have existed until latest Triassic time. Younger ones are found in England and South Africa, and at the close of the Jurassic a variety of very small mammals lived in Wyoming. Of these more will be said on a later page in connection with mammals in general.

Marine Invertebrates. — In Early Mesozoic time, the seas swarmed with a great variety of ammonites, which were the most significant marine invertebrates of Mesozoic times. Most of the genera and some of the species were spread widely throughout the world. Not only were

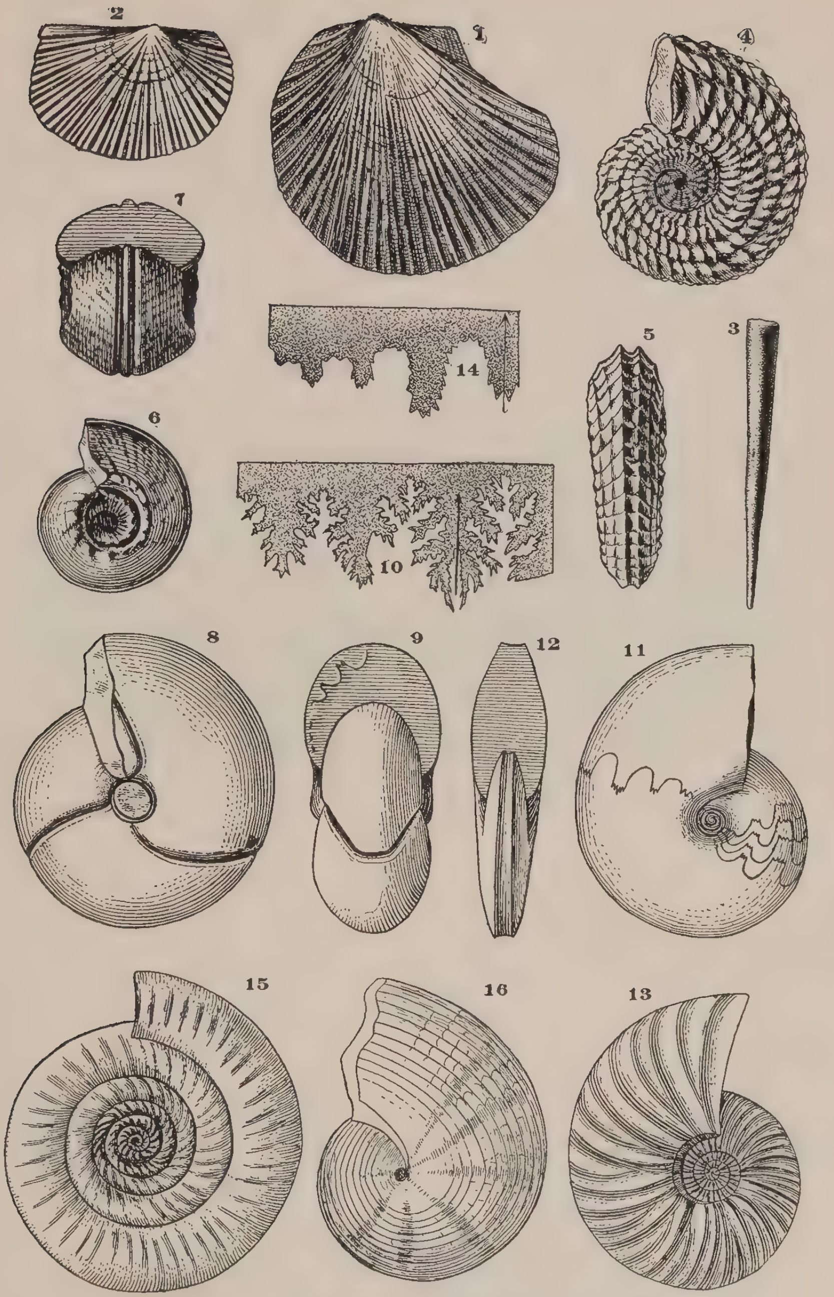


Plate 26. — Triassic bivalves (1, 2), belemnite (3), and ammonites (4–16).

Fig. 1, *Pseudomonotis subcircularis*, × $\frac{1}{2}$; 2, *Daonella dubia*, × $\frac{1}{2}$; 3, *Atractites burckhardti*, × $\frac{1}{3}$; 4 and 5, *Anolcites meeki*, × $\frac{1}{2}$; 6 and 7, *Tropites subbullatus*, × $\frac{1}{2}$; 8–10, *Joannites nevadanus*, × $\frac{1}{2}$; 11 and 12, *Meekoceras gracilitatis*, × $\frac{3}{4}$; 13 and 14, *Gymnotoceras russelli*, × $\frac{3}{4}$; 15, *Tropigastrites rothpletzi;* 16, *Sageceras gabbi*, × $\frac{1}{2}$. After J. P. Smith, from the U. S. Geological Survey.

these ammonites the most beautiful and characteristic animals of the Mesozoic seas, but also the highest expression of invertebrate evolution in agility and in predaceous ability. The forms of the Permian gave rise to a wonderful evolution in the Triassic, but were almost exterminated at the close of this period; another rapid evolution took place in the Jurassic out of a few forms, but with the Lower Cretaceous the group began to show decline, and before the close of the Mesozoic it had died out completely.

Ammonites have already been described in Chapter VI, but a few further details may here be added. Their shells were exceedingly varied in size, shape, and ornamentation. Probably the average size was between 3 and 4 inches, although one form in the Upper Cretaceous of Germany (*Pachydiscus seppenradensis*) attained a diameter of 8 feet. They appear to have been better swimmers than the nautilids of the Paleozoic seas, and therefore crawled less over the sea bottom. The name comes from a fancied resemblance of the shells to the horns of rams, pictured as one of the attributes of the Egyptian deity Ammon.

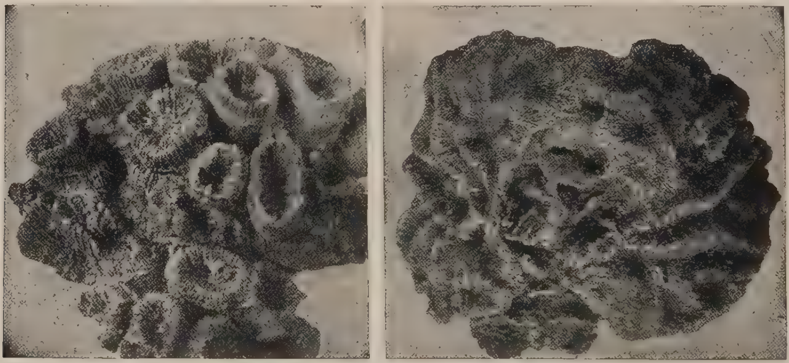


Fig. 97. — Two kinds of Jurassic reef-making corals (Hexacoralla). Right, *Latomæandra seriata;* left, *Thecosmilia trichotoma.* Similar corals are the main reef-builders in present oceans.

Ammonites are distinguished chiefly by the nature of the partitions (septa) between the chambers of the shell, which attain a much greater degree of complication than in the earlier nautilids. This latter fact makes them especially valuable in deciphering the chronology of the Mesozoic, since this complication is progressive with time.

Belemnites were also characteristic of the Mesozoic, and were the ancestors of the modern squids. They were likewise very active, carnivorous cephalopods which fed on fish, crabs, and molluscs, but unlike the ammonites, they had no external shells. They appear to have had only six arms, whereas living squids have ten. Among fossils, the part of the internal skeleton usually preserved is the *guard*, a more or less cigar-shaped, solid, calcareous body, sometimes 2 feet long and 4 inches thick (Pl. 26, Fig. 3).

In the Triassic, sponges are not well known, but in the Jurassic they were locally very common and in places the calcareous kinds made reef limestones. Other reef limestones were made in the Late Triassic by the modern corals (Hexacoralla); these reefs occur in the Tyrolian Alps through a thickness of 4000 feet of dolomites, and other extensive ones are known in the Himalayas and in the Pacific geosynclines from California to Alaska. In the Jurassic the reef limestones are equally common and far more widely spread (Fig. 97). The modern echinids also occur in Triassic rocks, but are far more conspicuous and varied in those of the Jurassic. Lobsters and crabs (Fig. 98) are usually rare as fossils, but the former appear with the Middle Triassic and the latter with the later Jurassic; their remains are especially well preserved and common in the Upper Jurassic limestones of Solenhofen, Germany. The ancient Mediterranean (Tethys) and the Pacific Ocean were the main centers of evolution for the marine life of Mesozoic time.

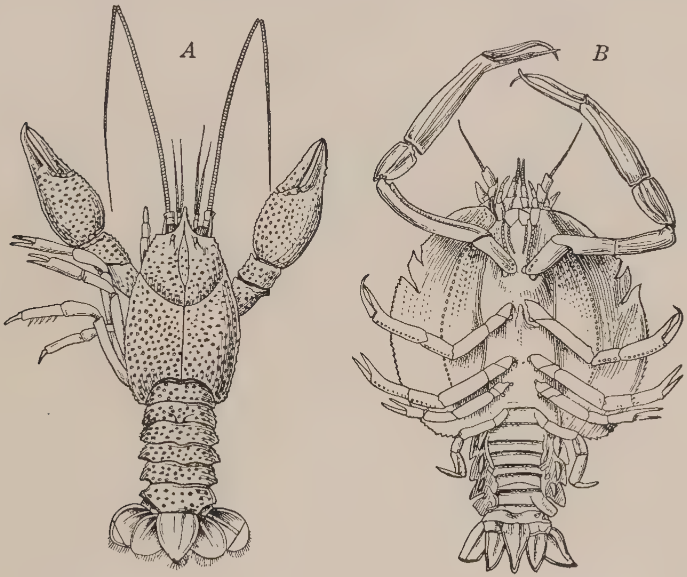


FIG. 98. — Jurassic arthropods. *A*, *Eryma*, a lobster; *B*, the crab *Eryon*. After Oppel, from Neumayr's *Erdgeschichte*.

CHAPTER XVI

LAND REPTILES AND TOOTHED BIRDS OF MEDIEVAL TIME

DINOSAURS

Bird-like tracks on the red sandstones of Upper Triassic age have been known for a century in the quarries of the Connecticut Valley (see Fig. 95). Some of these tracks are but an inch long, and others about 2 feet. Many of them are so like those made by three-toed birds that the geologists of the first half of the past century regarded them as made by birds. Now, however, they are known to have been made by reptiles, and chiefly by dinosaurs.

Unlike other reptiles (lizards, crocodiles, turtles), which sprawl because their short legs spread sidewise from their bodies, the dinosaurs carried their bodies well up off the ground with the legs vertical beneath as in the mammals. They were therefore well adapted for running, either on all four limbs (quadrupedal) or on the hind legs only (bipedal). As a group they show a most amazing range of size and shape, for they adapted themselves to all sorts of habitats, and during their heyday occupied every possible niche in the economy of nature, as do the mammals in the modern world. Indeed, they constitute two distinct orders and no fewer than seven suborders.

The Mesozoic lands were dominantly under the control of these "terrible reptiles," or dinosaurs, the most extraordinary animals the world has ever seen. Arising probably in the later Permian, they spread over all the lands, but are best known from their remains in North America, East Africa, Mongolia, and Argentina. In their time they were the highest expression of life, both as to body structure and as to wisdom, yet the brain in the largest of them did not weigh more than 1 pound to 30-odd tons of flesh, while the average man has 3 pounds of brain to 150 pounds of body weight. In other words, the medieval world was characterized by brute strength and low mentality.

The dinosaurian career was not a short one, but lasted something like 110 million years, twice as long as the subsequent mammalian age. Nevertheless out of the dinosaurs came no higher dynasties.

Like the majority of other reptiles, most of the dinosaurs reproduced through eggs, fossil examples of which have recently been found in Mongolia (Fig. 106) and in Wyoming.

Dinosaurs were superlatively low in brain power, and yet the nerve canal in the sacrum, that portion of the vertebral column which lies between the hips, was of startling dimensions, and shows that this part of the spinal cord, from which the nerves went out to the great muscles of the hind limbs and tail, was not less than twenty times the mass of the brain. As some one has said, the dinosaurs had more sense in their hips than they had in their heads! In any event, they had enough sense to eat when they were hungry, and anything more was superfluous.

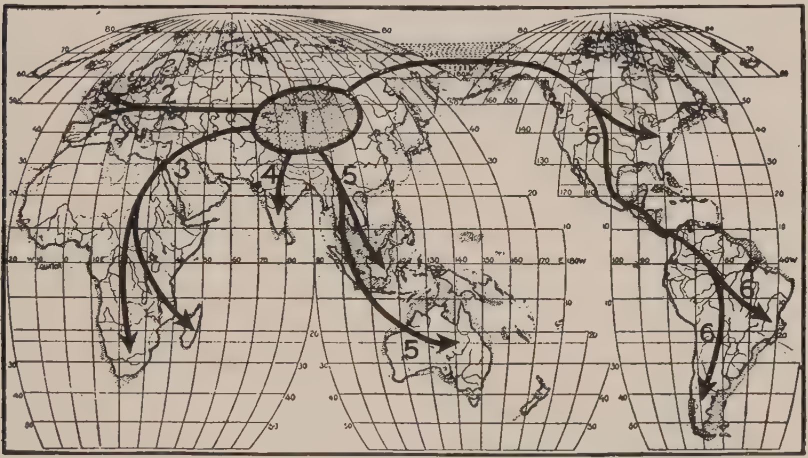


Fig. 99. — Map showing the generating center (1) of land life after middle Mesozoic time, and the migration routes from Holarctica into the rest of the continents. Homalographic projection. After Osborn.

Among the dinosaurs were huge beasts of prey with bird-like feet and eagle-like claws, running on their hind legs after the fashion of ostriches (Fig. 101); associated with these were other bipedal types, but of sluggish habits and with duck-billed muzzles, feeding on the vegetation of the swamps and water places; hugest of all were the sauropods (see Fig. 102), vegetarians walking on all fours, with more or less pillar-like hind legs, long snake-like necks, long tails, and a length of 60 to 80 feet.

Most curious of all, however, were the armored types, bearing plates and spines; these were also plant-feeders and quadrupedal in gait (Fig. 104). Finally, toward the close of the medieval era there appeared a very diversified horde of large rhino-like forms known as the ceratopsians (Fig. 105). It is these many kinds of strange medieval brutes that we are to study in this chapter.

In America, remains of dinosaurs are most frequently found in Wyoming, Colorado, Montana, and Alberta. Probably the richest quarry for these reptiles is in the Vernal Valley of northeastern Utah, 80 acres of which are now set apart as the Dinosaur National Monument. Here the animals appear to have been mired in quicksand, and the articulated skeletons lie over one another in a sandstone that now stands vertical due to crustal folding during the Laramide Revolution. It is from this quarry that most of the fine dinosaur skeletons in the Carnegie Museum at Pittsburgh and in the National Museum at Washington have come.

The Two Dinosaurian Orders. — During the present century it has become evident that the dinosaurs are not of a single line of descent, as was formerly thought, but that there are two such phylogenetic lines; for the present, however, we are continuing to use the term dinosaur, although it covers animals superficially alike, owing to parallel adaptation, but not really related. One of these lines of descent is called Saurischia, in view of the fact that the pelvic bones are similar to those in saurians or lizards; the members of this group are related to the crocodiles and alligators. The other line is known as the Ornithischia, because it has a birdlike pelvis. Both orders arose in swift-running bipedal forms probably in Late Permian time, and originally both had five functional toes on each limb, instead of the four or three found in later forms.

Of the Mesozoic reptiles and dinosaurs that lived in the cooler uplands far away from the sea we know nothing, the forms familiar to paleontologists being of the warm lowland swamps along river courses and rarely of tidal marshes along the sea front (East Africa). All of the dinosaurs died out with the Mesozoic era, and it is probable that their extinction was due to the vanishing of the lowlands and the introduction of winters at the close of the Mesozoic era. In Cretaceous times, Alberta had many dinosaurs, but if any were alive there now, none could survive the present winters, and accordingly the climate of their time must have been much milder at that latitude.

SAURISCHIAN DINOSAURS

The Carnivorous Theropoda ("beast-footed"). — The light-bodied, long-necked, and long-tailed type of dinosaur, of carnivorous diet, occurs for the first time in the Upper Triassic sandstones of the Connecticut Valley. This animal is known as *Anchisaurus* (cf. Fig. 100). Out of this type developed the later flesh-eating forms, all of which were also bipedal in locomotion, with their greatest variety in Jurassic time, and their greatest size near the close of the Cretaceous. Their fore limbs were often absurdly small in proportion to those behind and were used for catching, holding, and tearing the prey. The hind limbs were long and powerful, the larger bones hollow as in other active beasts of prey, and the feet birdlike. The claws were long, curved, and sharp like those of eagles. The teeth were sharp, slightly curved, and dagger-like, often with serrate cutting edges to add to their terribleness. No fiercer biting head was ever evolved than that of the king-tyrant saurian, *Tyrannosaurus rex* (Fig. 101), of the latest Cretaceous of Montana and

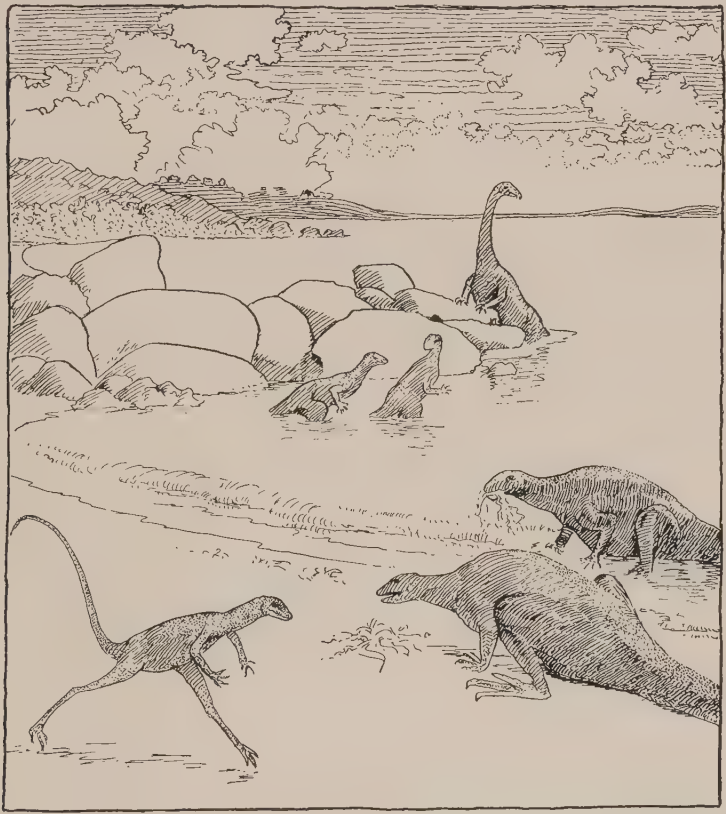


Fig. 100. — Triassic dinosaurs. In the left foreground, the small swift-running *Podokesaurus*, known from skeletal remains in Massachusetts. On the right, three sluggish plant-feeders of the type of *Anomœpus*, represented in the Connecticut Valley by footprints only. In the center, smaller forms similar to *Nanosaurus* of Colorado. After Heilmann, from Schuchert and LeVene's *The Earth and its Rhythms* (Appleton).

Wyoming — in respect to speed, ferocity, and bodily size, the most "destructive life engine ever evolved." In size the Theropoda ranged from several feet long, measured along the back, to 47 feet in *Tyrannosaurus*, with a height in the latter of 18 to 20 feet, and a weight exceeding that of the elephant. The skin in the Theropoda was probably naked, at least it was not defensively armored, though in some forms there may have been scales as in snakes.

One of the specialized stocks of theropod dinosaurs is that of the bird-mimics (Ornithomimes), which have a curious resemblance to the ostriches. They were slender-limbed carnivores with compact bodies, very long hind legs, and shorter, more slender arms, all provided with three clawed toes. The neck was long and slim, and the head birdlike in having no teeth and in having the jaws sheathed with a horny beak.

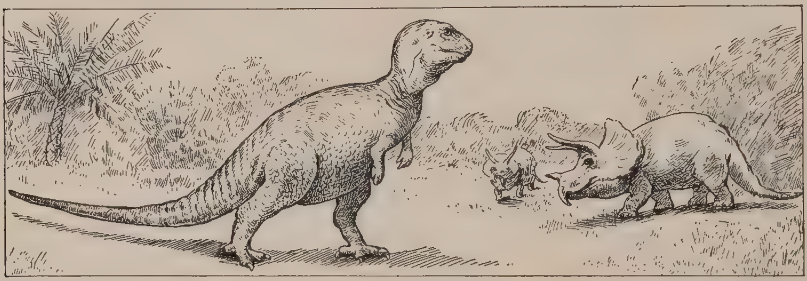


Fig. 101. — Restorations of the largest known carnivorous dinosaur, *Tyrannosaurus rex*, the "king-tyrant"; and of horned herbivorous dinosaurs (*Triceratops*). From the Late Cretaceous of Wyoming. After Osborn, and Gilmore.

The Giant Sauropoda. — The sauropods (" reptile-footed ") were ponderous animals and heavy of foot. They attained a world-wide distribution, being best known in the Late Jurassic of North America and East Africa, and in Late Cretaceous beds in western Argentina. The greatest of these was *Gigantosaurus* of East Africa, the largest land animal known, with a length of some 80 feet, 36 feet of which was neck, and a live weight of something like 40 tons. In this form alone, of all dinosaurs, the fore limbs were longer than the rear ones. The American *Brontosaurus* (" thunder saurian," Fig. 102) was about 65 feet in length, but heavier in construction, weighing more than 30 tons. It also had a long tapering neck and tail. The brontosaurs are thought to have lived for the most part in swamps of tidal river valleys (Rocky Mountains) and in fresh-water marshes along the seashore (Africa), detaching the swamp plants with the claws and swallowing their food without mastication.

Diplodocus carnegiei, " the animal that made Paleontology famous," was lighter in build though long and slender, with 10 of its 87 feet of length taken up by a whiplash-like tail of unknown use. The ponderous size must have given these sauropods a certain immunity from attack, while their chosen haunts kept them out of competition with fiercer kin.

The Sauropoda may not have been egg-layers.

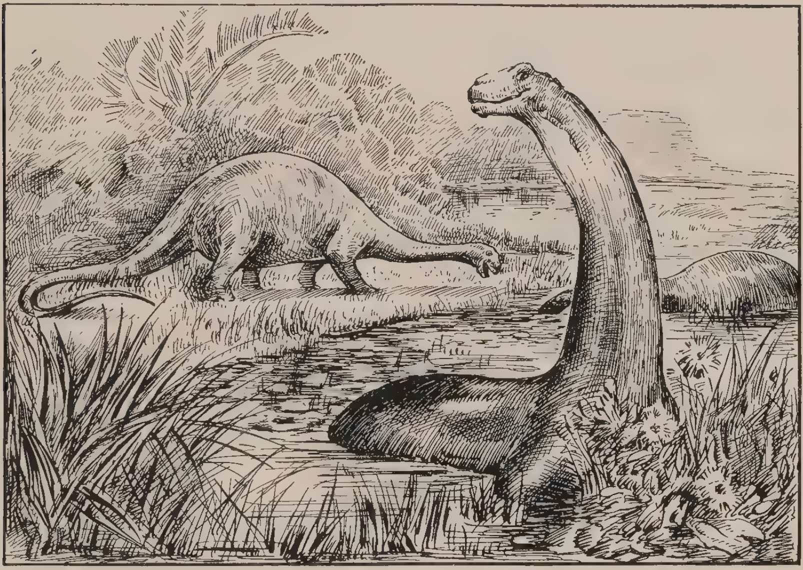


FIG. 102. — Restoration of the gigantic Late Jurassic sauropod dinosaur, *Brontosaurus*, of Wyoming. Weight of animal, over 30 tons. After Osborn.

ORNITHISCIAN DINOSAURS

All the remaining dinosaurs are of the order Ornithischia. These are rare in the Triassic, fairly common in the Jurassic, and in great diversity during Cretaceous time. In all of them, the front of the mouth is without teeth and is sheathed in a horny beak like that of a turtle, but farther back the jaws have abundant grinding teeth, since these dinosaurs are all herbivorous in diet. Nearly all have flattened hoofs instead of claws.

The Bipedal Ornithopoda (Fig. 103). — In the more or less amphibious and thin-skinned ornithopods (" bird-footed ") the muzzles terminated in a horny sheath, making a broad beak as in ducks or turtles; they are therefore also called the duck-billed dinosaurs. These forms, from 15 to 30 feet long, lived for the most part in water, where they cropped the plants with the sharp edges of their toothless beaks. In the back part of the jaws were wonderful magazines of successional teeth, with which they ground the food plants before swallowing them. When these teeth were completely worn away through grinding at the top, new ones came up from beneath to take their places.

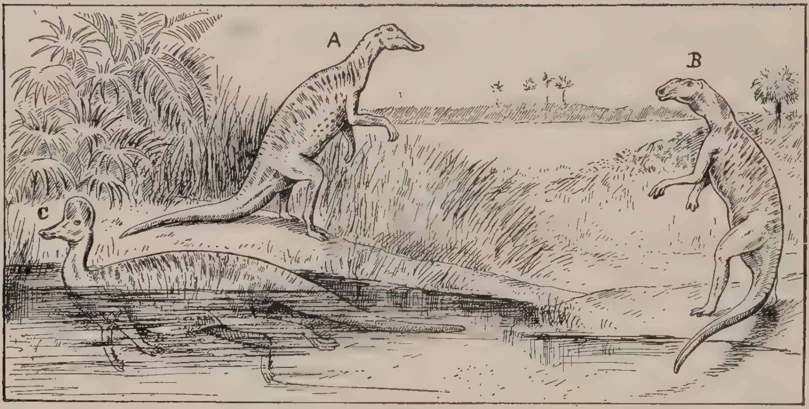


FIG. 103. — Restorations of "duck-bill" dinosaurs of the Late Cretaceous of Alberta, Canada. *A*, typical "duck-bill," *Trachodon; B*, hooded "duck-bill," *Corythosaurus; C*, crested "duck-bill," *Kritosaurus*. After Brown and Deckert, from Osborn.

The hind legs of these bipedal herbivorous dinosaurs were large and powerful, and on land were the essential means of locomotion. Their hands were webbed, and used for paddling, and the long, flattened tail allowed them to scull about in the water as do the alligators. The duck-bill mouth is further evidence that they dwelt much in water.

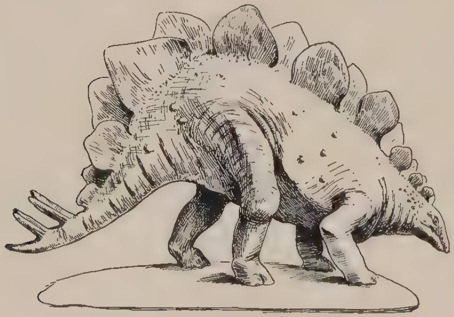


FIG. 104. — Restoration of an armored herbivorous dinosaur, *Stegosaurus*, from the Late Jurassic of Wyoming. Weight of animal, about 10 tons. After Gilmore.

The Armored Stegosauria (Fig. 104). — In Jurassic time there developed out of the duck-billed forms a most bizarre stock of sluggish, heavy-limbed quadrupeds, browsing on leaves and twigs very much as do the living tortoises. These were the plated and armored dinosaurs, animals that in some forms attained a length of 20 feet and a weight of 10 tons. Their habitat appears to have been completely away from the water on the dry land, where they were subject to the attacks of their carnivorous colleagues, hence the necessity of a protective armor. They returned to the ancestral locomotion on all fours, and specialized in the production of an elaborate series of bony outgrowths of the skin.

The narrow-bodied *Stegosaurus* (" covered saurian," see Fig. 104) was armored with a double row of large upright bony plates ranging down the back from the head to near the end of the lashing tail, there to be replaced by two or more pairs of long sharp spines, making the tail a " huge battle mace." All of these bony outgrowths were provided with horny sheaths. Over the hip area the plates were more than 2 feet high, 30 inches long, and 4 inches thick at the base. The tail spines attained to a length of about 2 feet. In the skin were other bony nodules. Doubtless when the stegosaurs were attacked, they drew their head and limbs under the body as do the armadillos and porcupines, relying on the dorsal armor for protection against an attack from above, while they slashed their powerful tail from side to side to ward off a flank attack. Another group, the ankylosaurs, were broad-bodied and plated all over, resembling in many ways the " horned toads " of Texas — animals that are true reptiles and not toads at all. Both these dinosaurian stocks died out during the Cretaceous, and appear to have been restricted to North America.

In *Stegosaurus* the small size of the brain in proportion to the body weight is especially noticeable, the brain weighing but $2\frac{1}{2}$ ounces as against fifty times that weight in the elephant of lesser bulk.

The Horned Ceratopsia. — Probably the most interesting of all dinosaurs are the horned types, first discovered in Wyoming and Colorado. These horned forms are characterized by the hugeness of the heads, in contrast to the comparatively small ones in most other dinosaurs. They were creatures with the general proportions of an overgrown rhinoceros (Fig. 105). The first form discovered was called *Ceratops* (" horned face "), and this has given the name to the group. The body was usually very large, barrel-shaped, with four short but stout legs. The tail was massive, but relatively short. The heads appear to be wide and long, being drawn out backward over the neck into a prominent pro-

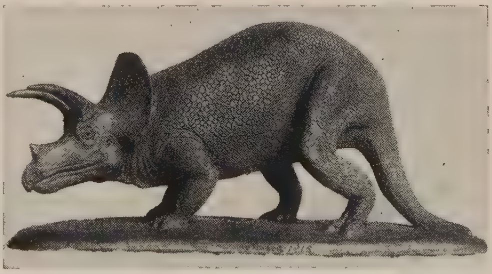


Fig. 105. — The horned dinosaur *Triceratops*, as restored by C. W. Gilmore for the United States National Museum. Note the horns for offensive warfare, and the defensive armor formed by ossicles in the skin.

tective frill, usually 4 to 6 feet long but reaching 8 feet in *Torosaurus*. It was to this frill on the under side that were attached the powerful muscles of the neck. In some there was a short horn over the nose, and in others a long one, and over the eyes there were other horns, which again may be long or short; in *Triceratops* (see Fig. 105), there were three prominent horns. Some of the horns had a length of 3 or even 4 feet, and all the cores of bone were sheathed in horn. In addition, there were still other smaller horns along the edge of the frill, or the latter was drawn out into long horns. The muzzles were also covered with horn as in turtles, and the jaws were replete with grinding teeth. The brain did not exceed 2 pounds in weight.

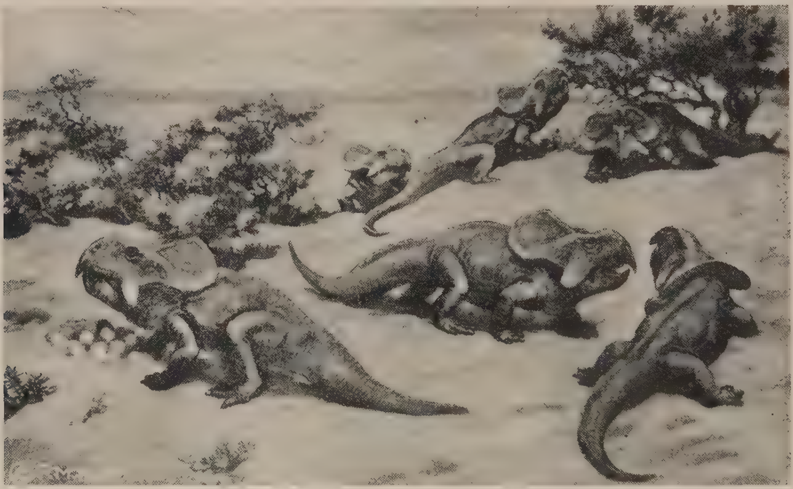


FIG. 106. — *Protoceratops*, a dinosaur with a large head and about the length of a crocodile. Its skeletons and eggs are common in the Gobi Desert of Mongolia. Painted by Charles R. Knight for the Field Museum of Natural History, Chicago.

The ceratopsian stock originated in Asia, in the hornless *Protoceratops* (Fig. 106), the well known egg-laying dinosaur of Mongolia, of which the American Museum of Natural History in New York City has a dozen skeletons and 72 skulls, of all ages from unhatched young in the egg to the full-grown animal. All the horned forms, however, appeared " ready-made " in the Upper Cretaceous (Judith River formation) of the Great Plains of North America and were among the last of the dinosaurs to die out. Some of them were larger than elephants, attaining a length of 20 feet and weighing in the flesh up to 10 tons.

PTERODACTYLS

After the dinosaurs, the most extraordinary and characteristic animals of the lands during Mesozoic time were the dragons of the air, known as pterodactyls. These flying reptiles were more or less batlike in appearance, and flew perhaps even better than the associated medieval birds. The largest ones had the extraordinary wing-spread of 25 feet. The skeleton, however, was of very light construction, and it is probable that even the largest forms did not exceed 30 pounds in live weight; their bodies were, in fact, but an appendage to a pair of wings.

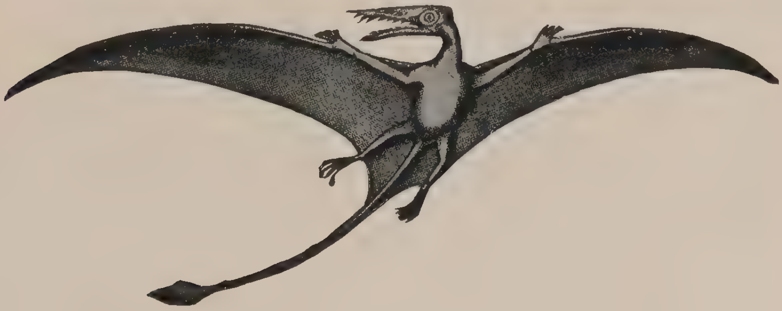


Fig. 107. — Jurassic "dragon of the air" or pterodactyl (*Rhamphorhynchus phyllurus*) × $\frac{1}{14}$. After O. C. Marsh.

The heads were usually much elongated, and the jaws generally provided with an abundance of slender, pointed, and more or less curved teeth for catching the prey, the animals being wholly carnivorous. In some forms the anterior part of the head appears to have been covered with a horny beak as in birds and turtles. The skin was evidently naked.

Probably the most striking single character of the pterodactyls was the elongation and modification of the front limbs into flying organs. This was especially true of the fifth or wing finger, which in the genus *Pteranodon* reached a length of 5 feet. To this was attached the wing membrane, a very flexible leathery skin like that of bats.

Skeletons of pterodactyls occur in greatest variety in the Jurassic strata of western Europe. In America, single bones are known in late Jurassic deposits, but the group attained its maximum size in the Cretaceous, when toothless *Pteranodon* sailed far out over the chalk seas of Kansas dipping up fish.

TOOTHED BIRDS

It is generally thought that the birds were evolved from a speedy, long- and slender-legged bipedal reptile, living in a cool desert of Late Permian time. As fossils, they appear for the first time in the Late Jurassic, and represent one of the most remarkable advances that the life of the period has to show. As yet, only a single kind of Jurassic bird has been found, and this is from the highest division, near Solenhofen, Germany. This bird, about the size of a large pigeon, is called *Archæopteryx* (Greek for *ancient wing*). It has many points of resemblance to the reptiles, and many characters which recur only in the embryos of modern birds. The jaws were set with a row of small teeth (see Fig. 108). The long reptilian tail had at least twenty pairs of long ornate feathers.

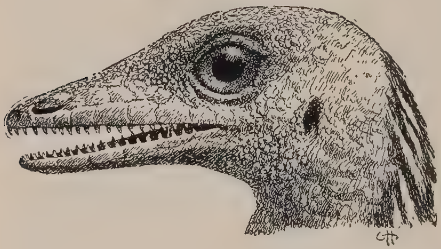


FIG. 108. — Head of *Archæopteryx*, as restored by Heilmann.

The oldest known American birds were strangely adapted for aquatic life, as are the penguins, and their remains are found far from the ancient shoreline in the Upper Cretaceous strata of Kansas. There are at least five species of these large reptilian marine birds, all of one genus; the one best known is *Hesperornis regalis*, the " regal western bird " (Fig. 109). They were wingless diving birds, feeding on fishes. In length they reached about 4½ feet, the legs were strong, the feet paddlelike, the neck long, the jaws set with sharply pointed teeth. There were no teeth in the front part of the skull, showing that the tendency toward toothlessness had already set in. The thigh bone projected at right angles to the body so that it is doubtful if the birds could stand on their legs at all. If these birds ever came on land, they must have progressed like the hair seals, prostrate on the breast. Hence they apparently present the most highly specialized development for aquatic life of any bird yet known.

Associated with *Hesperornis* are found very rarely other smaller toothed birds called *Ichthyornis* (Fig. 114), of a far more primitive and less specialized type. The two known species were about the size of pigeons, flew well, and appear to have fed on the wing over water. The body was covered with feathers, the neck was long, the head large and strong, with long jaws bearing many small, sharp, recurved teeth. The wings were large, long, and strong, the breastbone heavily keeled, and the legs and feet comparatively weak. The biconcave vertebræ are unlike those of any other bird, resembling rather those of fishes and some amphibians. As a flying form *Ichthyornis* is apparently nearer than *Hesperornis* to the central stem from which our modern birds have come.

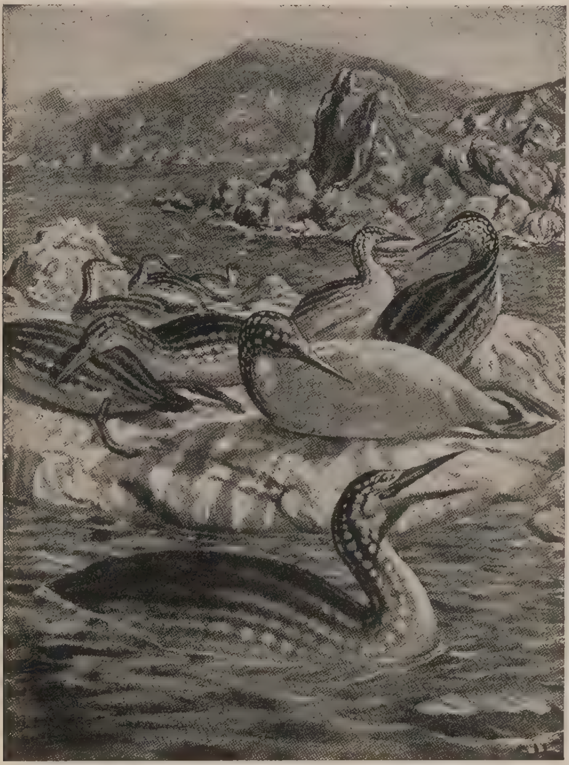


FIG. 109. — Swimming reptilian bird (*Hesperornis regalis*) from the Upper Cretaceous of Kansas. Restoration by Heilmann.

All toothed birds disappear during the close of the Mesozoic.

CHAPTER XVII

LATE MESOZOIC TIME

In the early part of the past century the European geologists were struck by the wide distribution of chalk deposits overlying the Jurassic and beneath the Cenozoic, and therefore characterized them as the Cretaceous system, from the Latin *creta*, chalk. In the course of their work in England and France, they added formations of other materials, because the fossils clearly linked them together. In this way the Cretaceous system came to embrace so great a mass of heterogeneous strata that with the continued increase of knowledge it became necessary to separate the formations into Lower and Upper Cretaceous divisions. This usage is now widely accepted. It is, however, becoming clear on the basis of oceanic spread that the Cretaceous formations show two cycles of submergence and therefore two distinct periods of time. In North America the older one is called Comanchian and the younger retains the older term Cretaceous. In this book, however, we shall speak merely of Lower and Upper Cretaceous.

Chalk was long believed to be an abyssal oceanic deposit like the present globigerina ooze found over great areas of the ocean bottoms, but the larger fossils in the chalks are indicative of shallow seas, and the formations are often accompanied by sands, while in closely adjacent areas the equivalent strata contain no chalk. Accordingly, it is now held that chalks are accumulations of organic materials made in the main by the calcareous skeletons of minute floating animals (Foraminifera, see page 46) and plants (algæ) that lived in warm clear-water seas adjacent to lowlands that furnished but little muds and sands.

Lower Cretaceous Geography

(Plate 27)

In North America, the Lower Cretaceous has three independent marine developments: (1) greatest in the Mexican geosyncline, extending widely over Mexico and northward across Texas and finally into Kansas and Colorado. This is the *Comanchian sea*. (2) A limited but important Pacific development known as the *Shastan sea*, to the west of the Central Cordilleran geanticline. (3) A Cordilleric invasion from the Arctic, about which at present little is understood other than

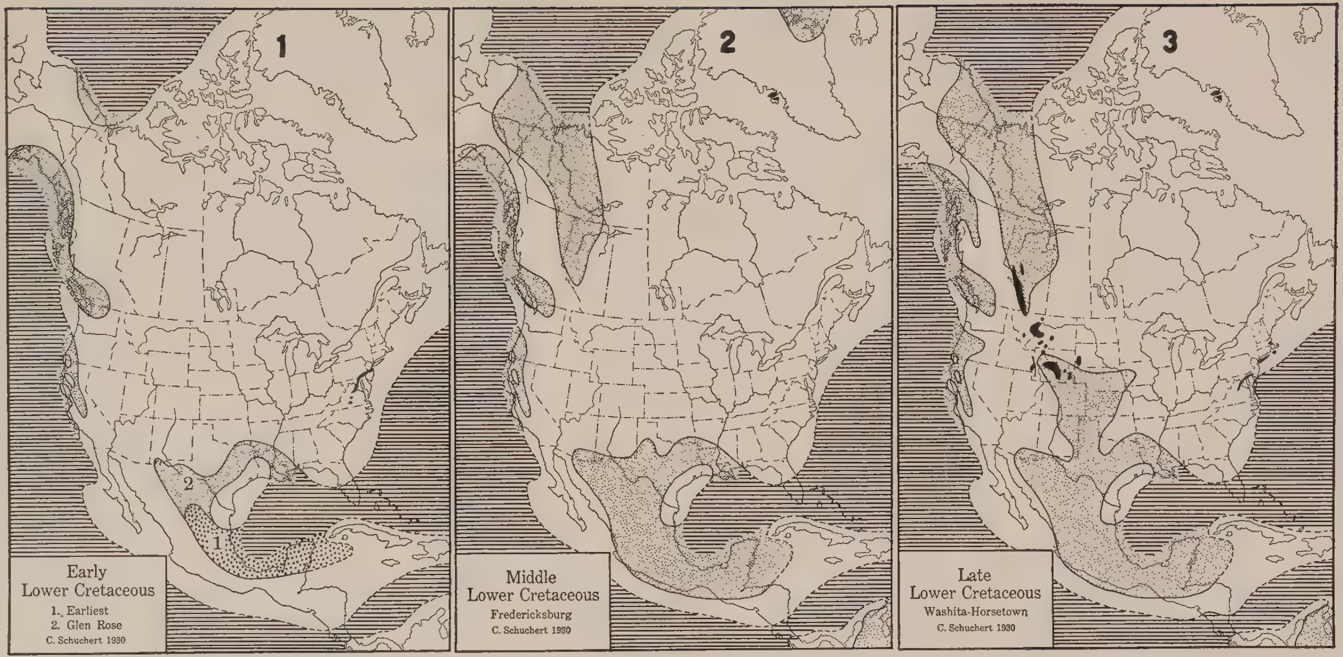


PLATE 27. — Paleogeography of Lower Cretaceous time.

Epeiric and shelf seas dotted; oceans ruled. Fresh-water deposits in solid black.

Note in Maps 1 and 3 the small eastern areas of fresh-water deposits (Potomac), and in Map 3 the wide distribution of the Kootanie formation, some areas of which are rich in good coals. Also note the vast flooding over Mexico; and along the Pacific the first clear evidence of shelf seas.

that it is the forerunner of the marked transgression here during Upper Cretaceous time. There are also important records of fresh-water deposition, the *Kootenai* strata of the Canadian Rockies and the United States, rich in coal deposits, and the *Potomac series* along the border of the Atlantic in the United States (see Pl. 27).

Comanchian Sea. — From southern Arkansas across Texas, and thence across almost all of eastern Mexico to the Isthmus of Tehuantepec, are found limestones and marls that are of Comanchian age. These are the deposits of the most extensive inundation by the oceans which befell Mexico and which was greatest here in middle Lower Cretaceous time. Central Texas is the typical area for these strata, and in Mexico the Comanchian beds are thought to go unbroken into those of the Upper Cretaceous. Late in Comanchian time the sea of the Texan area again began spreading northward across New Mexico and Oklahoma into Kansas and Colorado (see Pl. 27, Map 3). The thickness of Comanchian deposits varies between one and several thousand feet.

Shastan Sea. — The Shastan development is wholly distinct, faunally and lithologically, from the Comanchian one, from which it is separated geographically by the persistent Central Cordilleran geanticline (see Pl. 27, Map 2, and page 232). The faunas are of the Indo-Pacific realm. The Nevadian Revolution at the close of the Jurassic had greatly reduced the width of the Californic geosyncline, making of it a narrow but rapidly sinking trough throughout western California and Oregon. To the west of the trough lay small remnants of a borderland of which the present Coast Ranges are the remainder. Into this narrow trough the Shastan sea spread, depositing essentially sandy shales, the thickness of which attains about 10,000 feet in northern California.

Shastan deposits are also known in wide distribution in southern British Columbia and farther north along the Canadian and Alaskan coasts. Like the Triassic and Jurassic formations of this region, they include considerable thicknesses of volcanic material (lavas, tuffs, and ash beds), and in the Queen Charlotte Islands there is coal present.

In arctic and central Alaska, on both flanks of the Brooks Range, Lower Cretaceous deposits are of wide extent, and reach a thickness of over 10,000 feet. These strata in arctic Alaska were formerly regarded as of Jurassic time. The higher continental coal-bearing sequence of the same region, with a probable thickness of at least 15,000 feet, is now referred to the Upper Cretaceous.

Fresh-water Formations. — Turning now to the areas of fresh-water deposition, we find such of Lower Cretaceous age in southern Alberta (Crowsnest Pass) and southeastern British Columbia, east of the axis of the Rocky Mountains. These, the *Kootenai* swamp deposits, are chiefly sandstones and sandy shales. They contain many beds of good coal, estimated to total nearly 8,000,000,000 tons, of which about 400,000,000 tons is anthracite. The coal-bearing Kootenai is likewise present about Great Falls, Montana, and south into central Wyoming (see Pl. 27, Map 3).

The second fresh-water area of deposition is best represented in Maryland, by the *Potomac series.* The rocks are exposed to the east of the Triassic outcrops, and still further eastward they gradually pass beneath the later Cretaceous and Cenozoic strata. This formation is notable for its porcelain and pottery clays and its introduction of the flowering plants, which were to come in strongly in the Upper Cretaceous.

Upper Cretaceous Geography

(Plate 28)

With the Upper Cretaceous, we come to a time of widespread flooding of the continent by a great epeiric sea, and of overlaps along the Atlantic and Gulf of Mexico borders and the Antillean islands, and into the Pacific geosynclines. *The Upper Cretaceous transgression, the world over, was probably the greatest of all geologic time.*

The Great Upper Cretaceous Flood. — Beginning in northern Alaska, a vast inland sea spread more and more down the Cordilleric trough until in the early Upper Cretaceous it united with a sea coming in through Mexico, and reached from the Cordilleran highlands almost to the Mississippi River (see Pl. 28, Maps 1 and 2). On the west, it was barred by the still rising Central Cordilleran geanticline, which furnished nearly all the sediments for the sea to the east. All of that portion of the sea to the north of Texas is known as the *Coloradic sea;* southward is the *Mexican sea.* Later in the Upper Cretaceous the through waterway failed, and the arctic sea gradually withdrew, leaving in its wake 15,000 feet of strata in Alaska, the youngest of which are mainly of fresh-water origin with coal beds. The deposits of the Coloradic sea are very variable from place to place, and are notable especially for the amount of coal which they contain. In general, they are thickest in the west, where the materials came from the periodically rising Central Cordilleran highlands, so that brackish and even fresh-water deposits are more frequent here than in the eastern part of the sea, and here is the greatest amount of coal (humic and lignite). Throughout the Rocky Mountains there are more than 100,000 square miles of coal-bearing lands.

The *Mexican sea,* connecting with the one from the Arctic to make the great flood, was an extension from the Gulf of Mexico, and in its spread-

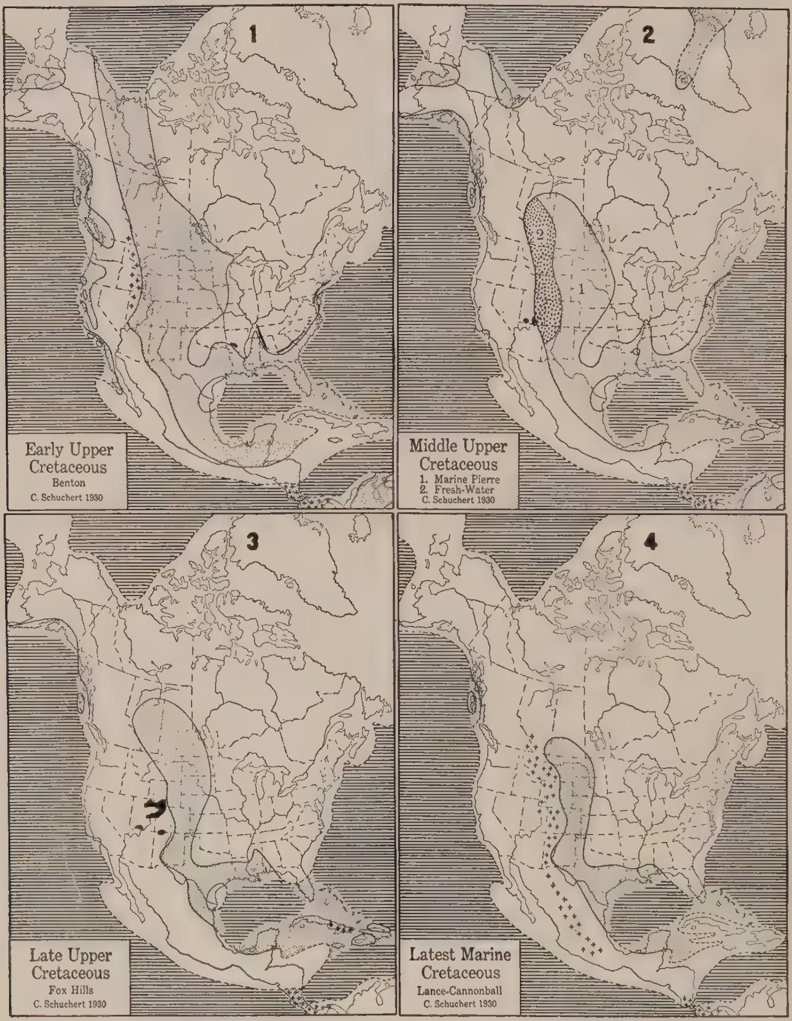


PLATE 28. — Paleogeography of Upper Cretaceous time.

Epeiric seas dotted; oceans ruled. Fresh-water deposits in solid black. Volcanic regions indicated by crosses. See Plate 29 for Late Cretaceous physiography.

Note in Map 1 the vast extent of the Cordilleric (Coloradic) sea, and in Maps 2 and 3 the extensive submergence of Antillia, along with volcanic activity; also the wide shelf seas along the Atlantic. The Cordilleric sea retreats more and more by way of the Gulf of Mexico. Also note the volcanic activity of Panama and Costa Rica, and the temporary closure of this old portal during latest Cretaceous time.

ing we see clearly the *first appearance of the Gulf* (Pl. 28, Map 1), due to deep subsidence which developed a far greater body of water than is now present. After the withdrawal of the Arctic sea, the waters from the Gulf persisted even into southern Canada until near the close of the epoch, though oscillating freely; as a consequence they left a medley of marine, fresh- and brackish-water deposits (Fox Hills, Lance, Cannonball, and Edmonton formations), accompanied frequently by andesitic lavas from the active volcanoes situated on the Central Cordilleran geanticline. The dating of these latest Cretaceous deposits, in order to establish the Cretaceous-Eocene boundary line, has long furnished, and still furnishes, one of the major problems in American stratigraphy. The oscillations and the general vanishing of the marine waters are prophetic of the coming Laramide Revolution.

The Mexican sea left its final record in marine deposits on the border line of Mexico (Eagle Pass) and in northeastern Mexico to the south of Monterey. South of this region, however, younger formations gradually vanish.

Late in Upper Cretaceous time, the flood spread over nearly all of the *Greater Antilles*, which became as well the site of innumerable volcanoes, so that the marine deposits are scattered through an immense amount of lava and ash formations. The waters of the Gulf of Mexico were then confluent with the Caribbean Sea, making the greatest American mediterranean of all time.

The deep subsiding of the Gulf also dragged down the entire *Gulf border* of the southern states, so that the seas spread across Louisiana and up the Mississippi Valley to southern Illinois, and across western Tennessee and Mississippi into southern Alabama and Georgia. This area had long been out of water, hence the Upper Cretaceous strata nearly everywhere overlap those of the Paleozoic, and in Georgia they rest on the ancient crystallines (Pl. 28, Maps 3 and 4). The deposits begin as a rule with sandstones and pass into clays and marls and locally into thick impure chalks.

Atlantic Border. — In addition to this great flooding of the interior portion of the continent, the Cretaceous waters overlapped upon the Atlantic border, laying down the oldest known shelf-sea deposits in North America. Upper Cretaceous formations are known all along the eastern border, either beneath, or inland of, the Cenozoic marine strata from Massachusetts to South Carolina (see Pl. 28, Map 2). They all dip seaward, though their original position is now warped, due to elevation in the west. The area yielding most information is in New Jersey and Maryland, where the strata consist in the lower half of gravels, sand, and clays with lignite, while the upper portion is made up of clays and sands becoming more and more glauconitic and finally going over mainly into greensands. Glauconite is made in clear-water seas at present, and this deposit is characteristic of the Atlantic Cretaceous and at times is also found in considerable quantities in the eastern Gulf border formations.

Central Cordilleran Geanticline. — We have now come to the place where it is necessary to understand the land barrier that keeps the Gulf and Arctic waters of the interior of North America apart from those of the Pacific. At least since Devonian time there is much evidence of the Cordilleric geosyncline (see Pl. 3), but of the region to the west of it little is known geologically back of the Upper Devonian. In the Late Devonian appears the first evidence of the British Columbic and Californic geosynclines, and between these western troughs and the Cordilleric one lies an elongate land that is part of what is to become the Central Cordilleran arch. Following the Devonian, the Pacific seaways are again obscure until Late Carboniferous and Permian times, when the western waters cross the area of the geanticline, in southern British Columbia (see Pl. 18, Map 2; Pl. 21, Map 2), and continue widely eastward across the Cordilleric basin into the interior sea. Again conditions are more or less obscure until Late Triassic time, when the longer northern part of the Central Cordilleran area is clearly present as a geanticline between the geosynclines. In the Late Jurassic the geanticline is far more clearly delimited between the eastern (Sundance) and western seaways. During this same period the arch is rising and furnishing 12,000 feet of sediments to the sea along the Pacific side of Alaska, and at the close of the Jurassic the area of the Sierra Nevada is added to the geanticline, so that the latter then extends unbroken from the Arctic into Central America. This latest Jurassic crustal movement also narrows the Californic and British Columbic geosynclines.

If we next study the paleogeography of Cretaceous time (see Pl. 27, Maps 2 and 3), we see the geanticline in its best development, with the narrow Pacific seaways to the west and a growing Cordilleric one to the east. The geanticline was, therefore, after Triassic time at least, a land barrier that kept the Pacific waters from mixing with those of the Arctic and the Gulf of Mexico.

Pacific Geosynclines. — The Californic sea of Lower Cretaceous time continued into the Upper Cretaceous, laying down, above the Shastan series, the younger and even thicker Chico sequence of sandstones and shales with local conglomerates and coal beds. Equivalent formations occur in the British Columbic geosyncline from Mt. St. Elias in Alaska and the Queen Charlotte Islands (11,000 feet) to Vancouver Island;

and in the Californic geosyncline from middle and southern Oregon as far south as central Lower California. Such great amounts of sedimentary material came in greater part from the Central Cordilleran arch and in least quantity from the remnants of the western borderlands that still barred the geosynclines from the Pacific (see Pls. 27, 28).

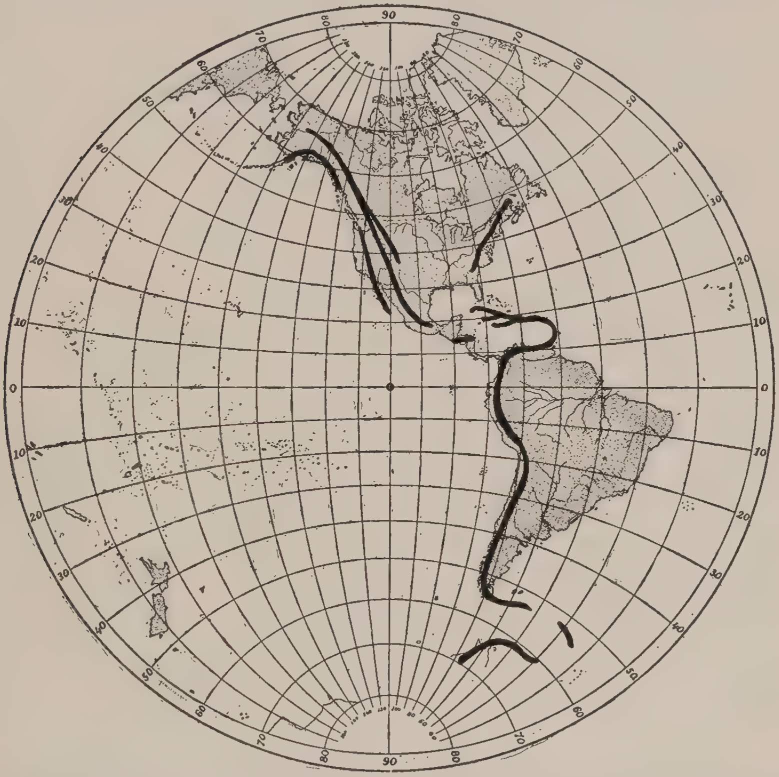


Fig. 110. — Stereographic map of the western hemisphere, after Penfield, showing the Laramide, Antillean, and Andean regions of folded mountains of Late Cretaceous origin. The Appalachian area was reëlevated but not folded.

Laramide Revolution

The close of the Cretaceous, and hence of the Mesozoic era, was marked by an extraordinary amount of crustal folding and thrusting in many parts of the world (see Fig. 110); in the Cenozoic most of these mountains were elevated into their present grandeur. In our own continent the folding started earliest in Alaska. Toward the close of the Lower Cretaceous the Pacific Coast ranges of Alaska were made, and probably the Brooks Range of the Arctic area as well. The latter range appears to have begun its rise early in the Lower Cretaceous as is in-

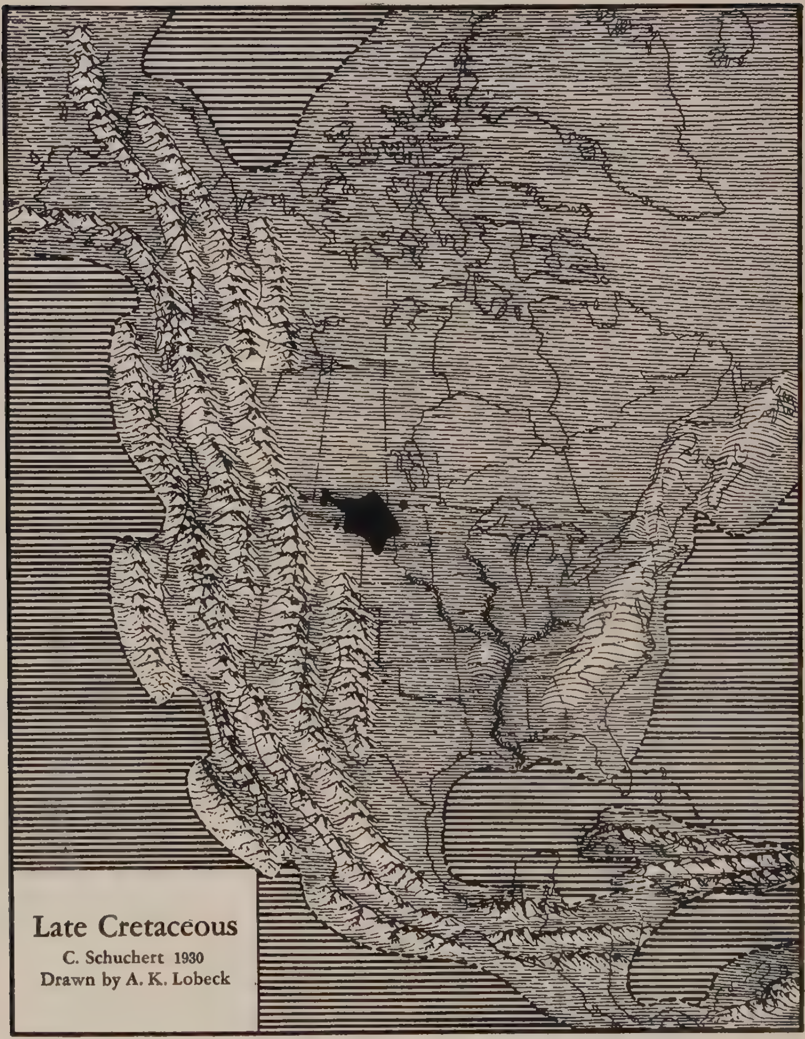


PLATE 29. — Latest Cretaceous paleophysiography.

Oceans ruled; lands in wavy lines.

Note that the continent is completely emergent, and that in the west it is newly risen into the Rocky, Cordilleran, and Pacific mountains (p. 233), while in the east the Appalachian area is again domed. Antillia and Central America also are mountainous.

The black spot is the area of latest Cretaceous fresh-water deposits. The drainage of the Mississippi system is well established.

dicated by the presence to the north of 10,000 feet of deposits, followed by 15,000 feet more of Upper Cretaceous strata. The Central Cordilleran highlands, which had been rising intermittently since the Middle Triassic, continued to rise and in the Late Cretaceous were studded with active volcanoes that extruded much lava and ash. These eruptions continued with unabated vigor to the end of Cretaceous time, and even into the early Eocene, and the volcanoes extended from Mexico City and Arizona north into Canada.

These volcanic eruptions were but symptoms of crustal movements, for mountain making of a folding nature, and thrusting toward the east on a vast scale, were going on during Late Cretaceous time, resulting in the formation of the Rocky Mountain system. (See Pl. 29.)

There were two times of folding, separated by an interval of inactivity when the essentially fresh-water deposits of the latest Cretaceous (Lance) were laid down to the east. The more intense folding, the actual Laramide Revolution, which closed the period and the era, transformed the sea to the east of the Central Cordilleran highlands into the very long Rocky Mountains proper and the Colorado ranges.

The Cordilleran geanticline itself, which had been steadily rising all through the Mesozoic, was elevated still further by the Laramide orogeny. It remains to-day a striking feature of Cordilleran geography, embracing as it does, from north to south, such markedly elevated areas as the Interior Plateaus of British Columbia, the Columbia lava plateau of Washington, Oregon, and Idaho, the Great Basin, and the Sonoran plateau of Arizona and northern Mexico.

The western part of South America was also involved in mountain making at this time. During the Paleozoic and Mesozoic there existed here a geosyncline, containing the Andeic inland sea, to the west of which stood a wide and repeatedly rising borderland furnishing rock materials. To the east of the sea lay a very extensive lowland, the Amazonian Shield, which in its history repeats the plains topography of the Canadian Shield. In the middle of Upper Cretaceous time, the Andeic geosyncline began to fold and rise into a mountain tract, the longest in the world. Beginning east of Trinidad off Venezuela, these mountains, the mighty Andes system, extend southwestward into Colombia and thence southward to beyond Cape Horn, a distance of nearly 5000 miles.

During the Cretaceous, and more especially in the Upper Cretaceous, came the downbreaking of the lands bordering the Indian Ocean, and the development here of the present geography. The first clear evidences of this foundering of the lands bordering the Indian Ocean are seen in the volcanic eruptions of Arabia in early Upper Cretaceous time, and later in the period the belching forth of lavas became more general in India. These are the most colossal fissure eruptions known to geologists, covering at least 200,000 square miles of India, as well as vast areas now buried in the depths of the Arabian Sea.

LIFE OF CRETACEOUS TIME

The most striking aspect of the land life of the Cretaceous was the full development of the modern floras, along with the culmination of the dinosaurs and toothed birds, and the rapid evolution of the archaic mammals. The floras held the prophecy of modernity, while the animals retained the culminating evolution of medieval life.

Modern Floras. — Probably the most significant event in the life of medieval times was the seemingly sudden appearance of the flowering plants in the late Lower Cretaceous, though scattering forms are known back at least to the Middle Jurassic. The floras of the Lower Cretaceous are everywhere divisible into an early and a late phase of development. The older ones are those of the Jurassic retained into Cretaceous time, and consist of ferns, rushes, cycads, and conifers. The rushes, however, had now dwindled into their present meagre representation, and the older Mesozoic ferns were giving way to modern ones. Finally, the cycads also began to wane, and their places were taken by the modern flowering plants or angiosperms.

This new or modern flora of flowering plants, when it appeared in the Cretaceous, already had a very wide distribution and a great diversification, all of which means a long antecedent existence. It was a hardwood flora, wholly of bushes and trees, and by Upper Cretaceous time had spread to Alaska and Greenland, where elms, oaks, maples, and magnolias then lived. It was also widely spread in the southern hemisphere.

At what time the herblike plants, the annuals and perennials, originated is not known, but some paleobotanists think they may have come with the Glacial period at the close of the Cenozoic era. Early in the Cenozoic, however, fruits, grasses, and cereals rapidly came into being, and these were of prime value in the ascendance of insects, birds, and mammals. It seems more than a coincidence that angiosperms should have arisen and become world-wide in dispersal before the widest deployment and most significant evolution of the mammals took place, and we may well believe that the primate line culminating in man could not have evolved but for the presence of this group of plants, since almost the entire plant food of man and his domesticated animals is supplied by the angiosperms.

When and where the flowering plants originated is still an "abominable mystery," as Charles Darwin said it was in 1879. The most acceptable hypothesis in regard to the matter is that they arose in a stress climate, either arid or seasonally cold, perhaps as far back as the Permian, and out of cycad-like forms. Their homes for a long time thereafter are thought to have been in highlands with stress climates, and it was probably not until Middle Jurassic time that a few of them obtained a foothold on the lowlands near sea-level. Just what it was that made possible the very rapid dispersal of the flowering plants in the Cretaceous is also unknown, but it is permissible to point out that the wide flooding of most of the continents in the later Jurassic shows that the lands were again near sea-level, and that most of the mountains had lost their former grandeur through erosion, bringing on world-wide lowlands with warm climates. At the same time, too, began to appear bees and butterflies, which are efficient agents in cross-fertilization. These more favorable conditions were taken advantage of by the angiosperms, and their more effective method of reproduction by carefully protected and nourished seeds doubtless contributed greatly to their success.

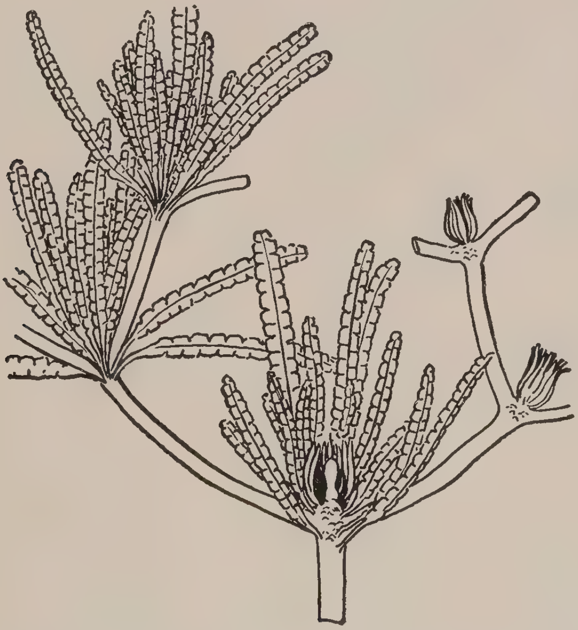


FIG. 111. — *Wielandiella*, perhaps the oldest known flowering plant, of a type transitional between gymnosperms and angiosperms. After Nathorst, from Scott's *The Evolution of Plants*. Reprinted by permission of Henry Holt and Company.

Whatever the cause of the rapid dispersal of the flowering plants, it is plain that with their spread the whole animal world of the lands began to be in a state of flux, changing into that of modern times.

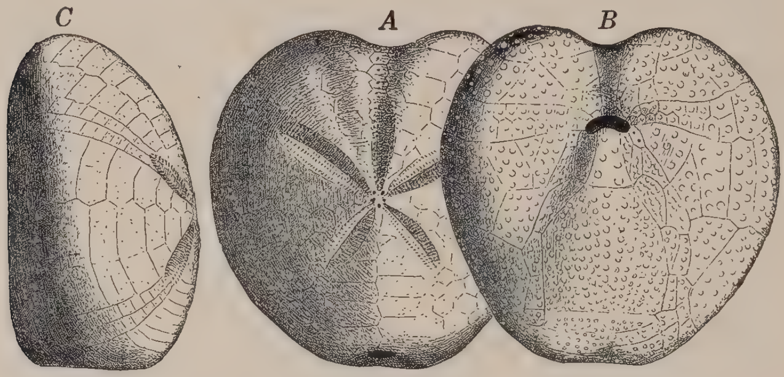


Fig. 112. — A Cretaceous heart-urchin, *Micraster*. After Zittel.

Marine Invertebrates. — The invertebrate life of the sea was not very different from that of the Jurassic, and only a few of the more marked changes need be noted. The sea-urchins were varied and prolific in the warmer seas, and the heart-urchins attained their climax of evolution in the Upper Cretaceous. Among the bivalves, true oysters and many oyster-like forms (see Fig. 113) were very abundant, while on the whole the molluscs were taking on the expression of modernity, through the elimination of the old stocks. The ammonites were still plentiful in the Lower Cretaceous, but showed a great loss of vitality,

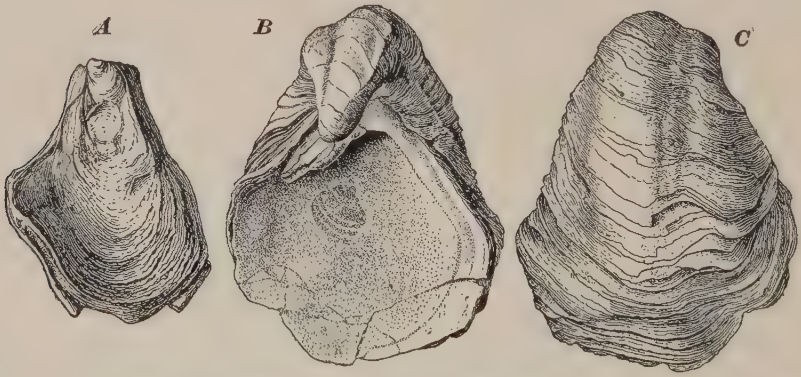


Fig. 113. — Oyster-like shells characteristic of the Lower Cretaceous (*Gryphæa mucronata*). After Hill and Vaughan, U. S. Geol. Surv. *A*, upper or free valve. *B* and *C*, lower or attached valves from the inside and outside.

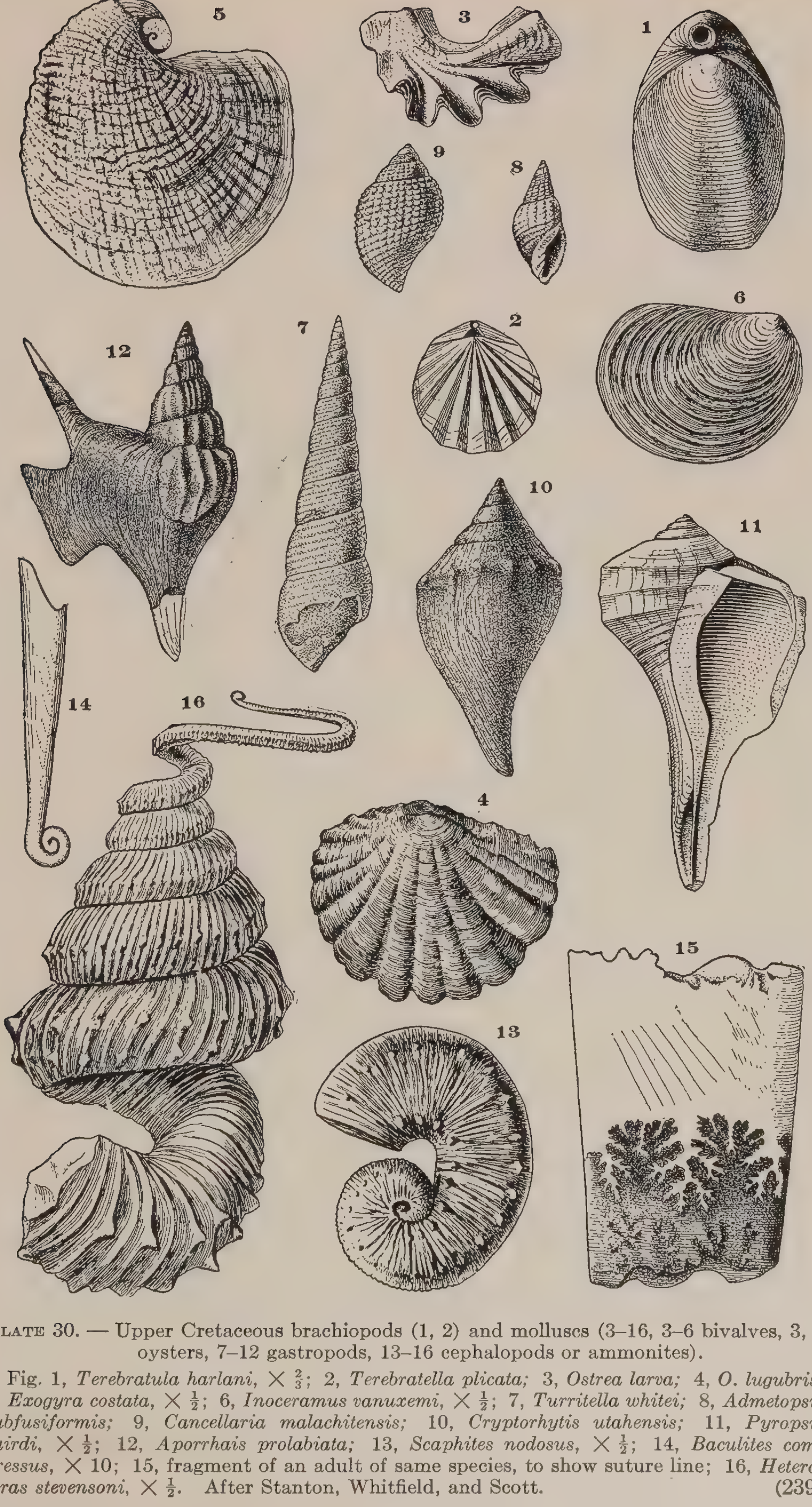


Plate 30. — Upper Cretaceous brachiopods (1, 2) and molluscs (3–16, 3–6 bivalves, 3, 4 oysters, 7–12 gastropods, 13–16 cephalopods or ammonites).

Fig. 1, *Terebratula harlani*, × $\frac{2}{3}$; 2, *Terebratella plicata;* 3, *Ostrea larva;* 4, *O. lugubris;* 5, *Exogyra costata*, × $\frac{1}{2}$; 6, *Inoceramus vanuxemi*, × $\frac{1}{2}$; 7, *Turritella whitei;* 8, *Admetopsis subfusiformis;* 9, *Cancellaria malachitensis;* 10, *Cryptorhytis utahensis;* 11, *Pyropsis bairdi*, × $\frac{1}{2}$; 12, *Aporrhais prolabiata;* 13, *Scaphites nodosus*, × $\frac{1}{2}$; 14, *Baculites compressus*, × 10; 15, fragment of an adult of same species, to show suture line; 16, *Heteroceras stevensoni*, × $\frac{1}{2}$. After Stanton, Whitfield, and Scott.

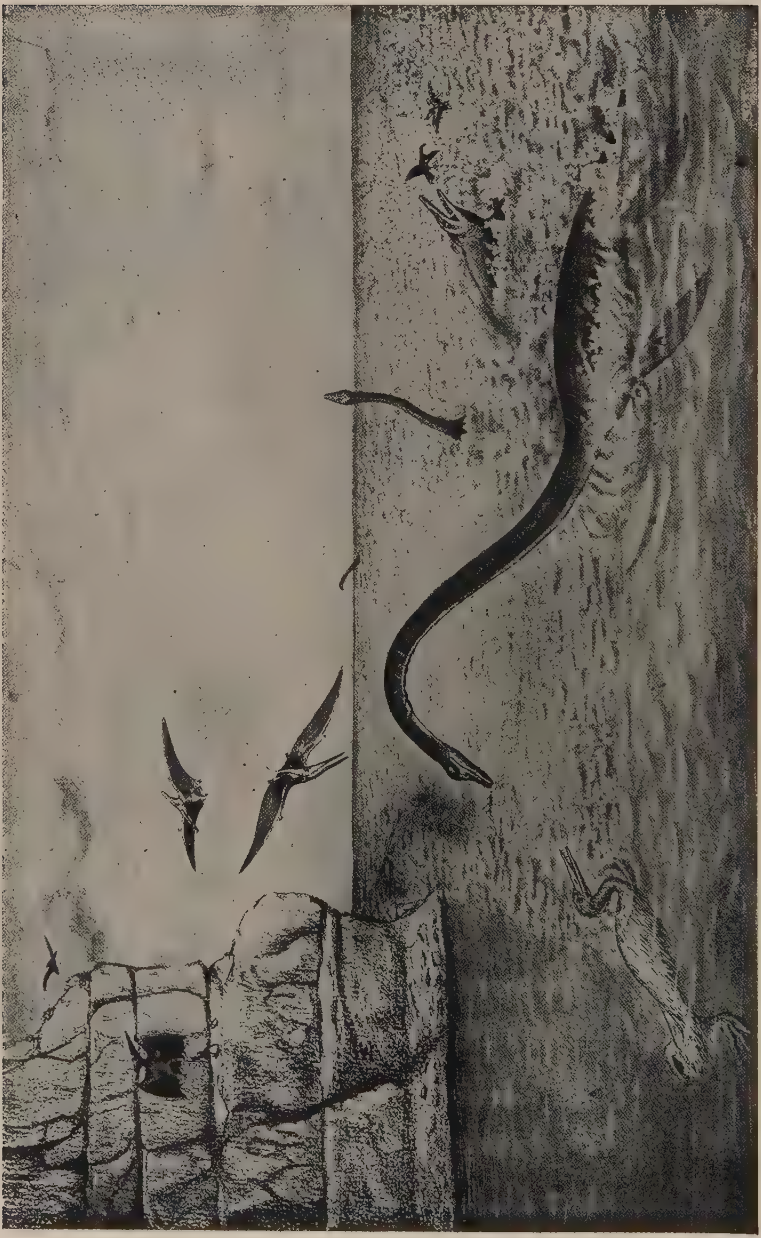


FIG. 114. — Vertebrates of the Chalk seas of Kansas. The long-necked reptile attacking the wingless reptilian bird (*Hesperornis*) is a plesiosaur (*Elasmosaurus*); the flying reptiles on the left are pterodactyls; on the right is a fish-lizard (*Ichthyosaurus*) attacking the winged reptilian bird *Ichthyornis*. After Williston. From University of Chicago Press.

in that few new stocks arose. By Upper Cretaceous time, racial old age was upon them, and they were making their last stand, the curious bottom-living forms being the last to vanish. Another critical period was at hand, and with the vanishing of the ammonites went the belemnites. There was also marked reduction among the reef corals.

Marine Reptiles. — The seas of Cretaceous time, as well as the lands, continued to be dominated by reptiles. In the Upper Cretaceous, the ichthyosaurs were vanishing, but the plesiosaurs attained their culmination, for a form has been found in Kansas which had a length of 40 to 50 feet (*Elasmosaurus*, Fig. 114). Most interesting of the newly appearing marine vertebrates were the scaled reptiles known as mosasaurs, which lived only during the Upper Cretaceous. These gigantic carnivorous lizards, ranging in length up to 35 feet, and with limbs modified into swimming paddles, swarmed in the shallow seas along the Atlantic and Gulf borders, and especially in the seas of Kansas (see Fig. 115). None of these marine reptiles survived the critical conditions brought on by the Laramide Revolution.

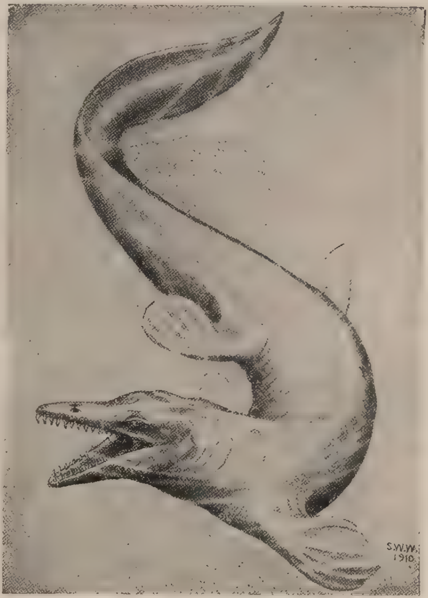


Fig. 115. — A scaled Upper Cretaceous mosasaur (*Clidastes*), from Kansas. Restoration by Williston, from University of Chicago Press.

Land Reptiles. — Almost nothing is known of the dinosaurs in the Lower Cretaceous of America other than fragmentary skeletons in the Potomac formation of Maryland, though they are commonly present in equivalent formations in Europe. During Upper Cretaceous time, however, these reptiles were varied and some of them large in size. The most characteristic were the horned Ceratopsia. The large duck-billed kinds were represented by distinctively American forms, both in the Rocky Mountains and in New Jersey. Large sauropods were rare; in fact, the only one known in North America occurs in New Mexico, though in Argentina they were common. Upon these various plant-feeding dinosaurs preyed the carnivorous types, among which was the king-tyrant saurian (*Tyrannosaurus rex*), the most fearful of all flesh-eating animals (Fig. 101). Not one of these monsters continued into Cenozoic time; they were blotted out by the destruction of their habitats when North America was elevated during the Laramide Revolution, and the climate became markedly cooler.

Birds. — Birds are represented in the Upper Cretaceous by the toothed forms described in an earlier chapter; and the flying reptiles, or pterodactyls, reached their culmination here in *Pteranodon.* Neither stock passed over into the Cenozoic.

Mammals. — Many jaws of diverse kinds of archaic mammals have been found in Late Cretaceous deposits of Wyoming and Montana, but they did not as yet play an important rôle among the land animals of their time; nearly all were small and of archaic character. Early in the Cenozoic (Fort Union) immediately after the dinosaurs had vanished, they began to attain larger size and tended to become the dominant animals of the lands. The most remarkable of these were five genera of primates, the stock to which man belongs.

Climates of Mesozoic Time

In Chapter XIV we have seen that in Middle Permian time the southern hemisphere was in the throes of a glacial climate, probably brought on because all the continents then stood high above sea-level and most of them were surrounded by young mountain ranges. The dry climatic conditions so general in the Permian continued throughout Triassic times, but there is no evidence of glaciation in the latter period. In the northern hemisphere, while there is no evidence of local glacial climates in the Late Permian, there are facts showing that the greater parts of the continents here had arid and possibly seasonally cool conditions. These prevalent climatic phenomena continued into the Triassic, and winters may have reappeared in latest Triassic and early Jurassic times, since the Jurassic insects of England are all small. The continents had, however, by this time subsided through gravity and erosion to lower levels, and early in the Jurassic the oceans began their recurrent march over the lands, attaining climax in the later part of this period. Now temperate and tropical climates generally prevailed over the continents even into high latitudes, though cool seas seem to have been present in northern Russia, where there are none of the coral reefs so widely spread farther south. It is, moreover, during the Jurassic and especially late in this period that we see the wide deployment of the warm temperate to tropical dinosaurs, and the mild conditions thus indicated continued to become more widespread into the Middle Cretaceous, when the continents were again flooded, and this time about as widely as they ever had been.

Tropical plants like palms, figs, and breadfruit trees then lived in the Great Plains country, and magnolias and breadfruit flourished even in central western Greenland, showing that the climate as far north as the Arctic Circle must have been at least warm temperate.

Early in the Upper Cretaceous we find the continents again emerging, tremendous mountains rising in western North and South America and all along the north side of Tethys far into Asia. With this uplift, widespread glacial conditions occurred in central Australia, and in very latest Cretaceous or earliest Cenozoic time there were alpine glaciers in Colorado. Accordingly winters had again returned to the Rocky Mountains, but in the lowlands the climate was probably like that of coastal North Carolina to-day.

When we follow the pulsing of life under these changing climatic conditions, both of the lands and of the seas, and among both plants and animals, we see in the Late Mesozoic a dying out of many races and a quickened evolution among the sparse remainders at the end of the Permian and in the Early Triassic. A marked diversification and increase in size in all the phyla then set in, and toward the close of the Jurassic there is a fullness of all kinds of life under the widely uniform and mild climates. This increase in variety and size continues into the Early Cretaceous, and now the angiosperms of the highlands are spreading into all the lowlands, and because of their presence the spell of the Cenozoic is felt everywhere. With the Late Cretaceous, a time of great organic struggle and dying out is again at hand, since the continents are emerging, highlands are appearing, the oceans are growing deeper, the climate is becoming variable, and cold winters are present over wide areas. The very same phenomena that we saw toward the close of the Paleozoic are now repeated, though not so intensely, in the Late Mesozoic and on into the Eocene, when we see increasing numbers of small " heralds " telling of a new organic world, that of the Cenozoic era.

CHAPTER XVIII

THE DAWN OF THE RECENT IN CENOZOIC TIME: AGE OF MAMMALS

Long ago a famous geologist said that the picture which Geology holds up to our view of North America during the greater part of Cenozoic time is in most respects more attractive and interesting than could be drawn from its present appearance. Then a warm and genial climate prevailed from the Gulf to the Arctic Ocean, and most of the continent exhibited an undulating surface of rounded hills and broad valleys covered with forests, inhabited by birds and animals far more varied than any of the present day, or wide expanses of rich savannah over which roamed countless herds of mammals, many of gigantic size, of which our present meagre fauna retains but few representatives.

During the rise of the science of Geology, the youngest era in the history of the Earth was named Tertiary, it being thought that all older time was comprised in but two other eras. Later came into use the term Quaternary, which included the youngest geologic formations of more or less unconsolidated materials scattered over the surface of the Earth. Since, however, Quaternary is not representative of an era of geologic time, but only of an epoch, and since we now recognize more than three eras, we had best abandon both Tertiary and Quaternary, and use only one term, Cenozoic (from Greek words meaning recent life). Recent time, according to the present author, starts when the Pleistocene continental glaciers began their final melting off northern Europe and North America, seemingly something like 20,000 years ago.

The Cenozoic era is the shortest one in the history of the Earth, and on the basis of radioactive minerals has a length of about 60 million years. Nevertheless, even though this era is only half the length of the Mesozoic and but one fifth that of the Paleozoic, it is certain, on the basis of diastrophism, that we are here treating of a natural era, since it is bounded on one side by the Laramide Revolution of the Late Mesozoic, and on the other by the Cascadian-Alpine Revolution, in the closing stages of which we are now living. It is apparent, then, that the revolutions of the Earth's crust are accelerating in rate of occurrence (time ratio, 5 : 2 : 1), but what this means in the eventual history of the Earth, or when the next grand time of diastrophism will appear, are unanswerable questions.

The separation of the Cenozoic into various subdivisions resulted from the study of the rich marine formations of the Paris basin, with their interbedded continental deposits. It became apparent as early as 1818 that the youngest strata had the greatest number of still living species, while the forms found in the oldest rocks had the least faunal resemblance to those of the present, and in the Cretaceous there were no species of the present living world. Hence the Cenozoic must be regarded as the era in which our present animal life dawned, and on the basis of the progressive change or evolution in its marine shells, it is divided into the following epochs: Eocene (dawn of the recent), Oligocene (little of the recent), Miocene (less of the recent), Pliocene (more of the recent) and Pleistocene (most of the recent).

It must be kept in mind, however, that these divisions do not have the importance of periods of other eras; they are epochs of time, with an average duration of about 12 million years, as compared with 30 million for the periods of the Mesozoic and 30 to 45 million for those of the Paleozoic. For this reason the Cenozoic is here treated regionally rather than epoch by epoch. If, however, the Cenozoic is to be divided into divisions with the semblance of periods, it can be done most naturally on the basis of diastrophism as recorded in mountain making.

Cenozoic Seas and Mountains

It has been increasingly apparent that after the Appalachic geosyncline was finally folded into mountains at the end of the Paleozoic, the Atlantic waters did not again spread through inland troughs, but transgressed over the eastern part of North America only as shelf seas, as they do at present. In the Mesozoic, inland marine sedimentation persisted only in the geosynclines of the West, which continued to afford access to the waters from the Arctic, the Pacific, and the Gulf until they too were elevated into mountains at the end of that era. With the Cenozoic, the whole central portion of the continent was clear of marine waters, which succeeded in making their impress only along the margins. That is, there were merely shelf seas, instead of the great epeiric ones that formerly spread far and wide over the interior. They oscillated back and forth as heretofore, but at their maximum they covered only 6 per cent (middle Eocene) of the present area of North America, and their average was about 3 per cent or even less (see Pl. 31).

Atlantic Border. — The marine record along the eastern side of the continent is the least in amount and the most broken of all. The entire northeastern corner was out of reach of invading waters after Early Permian time, and, save for slight overlaps in Massachusetts, no Cenozoic deposits are known north of New Jersey. That state, Maryland, Delaware, and Virginia have a limited development of early Eocene marine greensands and marls, not over 225 feet thick. This Eocene sea advanced across a land surface of Mesozoic strata that was nearly base-levelled, the contact between the two sets of deposits being an almost horizontal one. However, not a single species of the many Mesozoic animals is known to pass this break into the Cenozoic, indicating that the lost interval here is of great length.

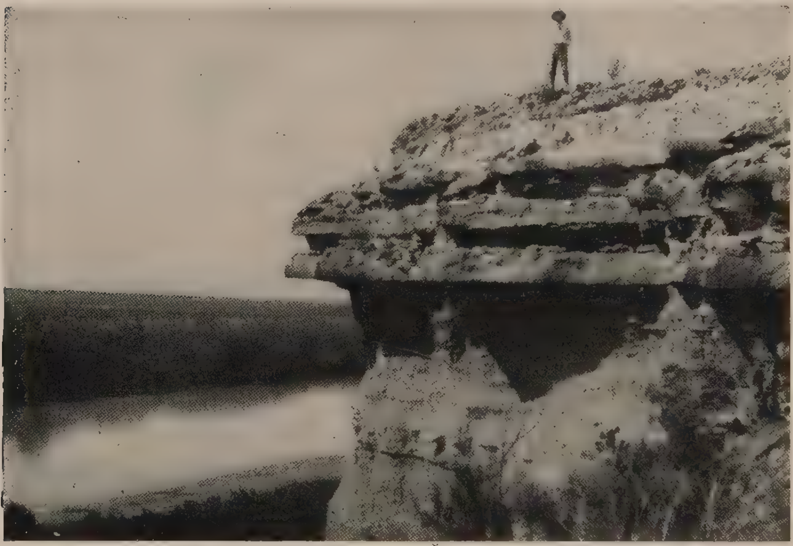


Fig. 116. — Projecting ledges of Eocene (Midway) limestone resting on Cretaceous shale (Escondido) at White Bluff, Rio Grande, Texas. Note the conformable contact. U. S. Geol. Surv.

The Oligocene sea came no farther north than South Carolina; that of the Miocene, on the other hand, laid down over the Eocene in Maryland, Delaware, and Virginia a series of sands, clays, marls, and diatomaceous beds a little over twice as thick as those of the Eocene, and also traversed what is now the outflung elbow of Cape Cod. Included in the Miocene deposits in South Carolina and Florida are the widespread phosphate rocks that help to make the United States the foremost factor in the world's phosphate supply. These phosphate beds are in the main formed by the accumulation of animal remains, and from them come enormous quantities of sharks' teeth, including those of the 60-foot *Carcharodon*, which once roamed the Atlantic seas. These cool-water Miocene faunas (Chesapeake formation) came from the Arctic, probably due to the breaking down of the land-bridge between

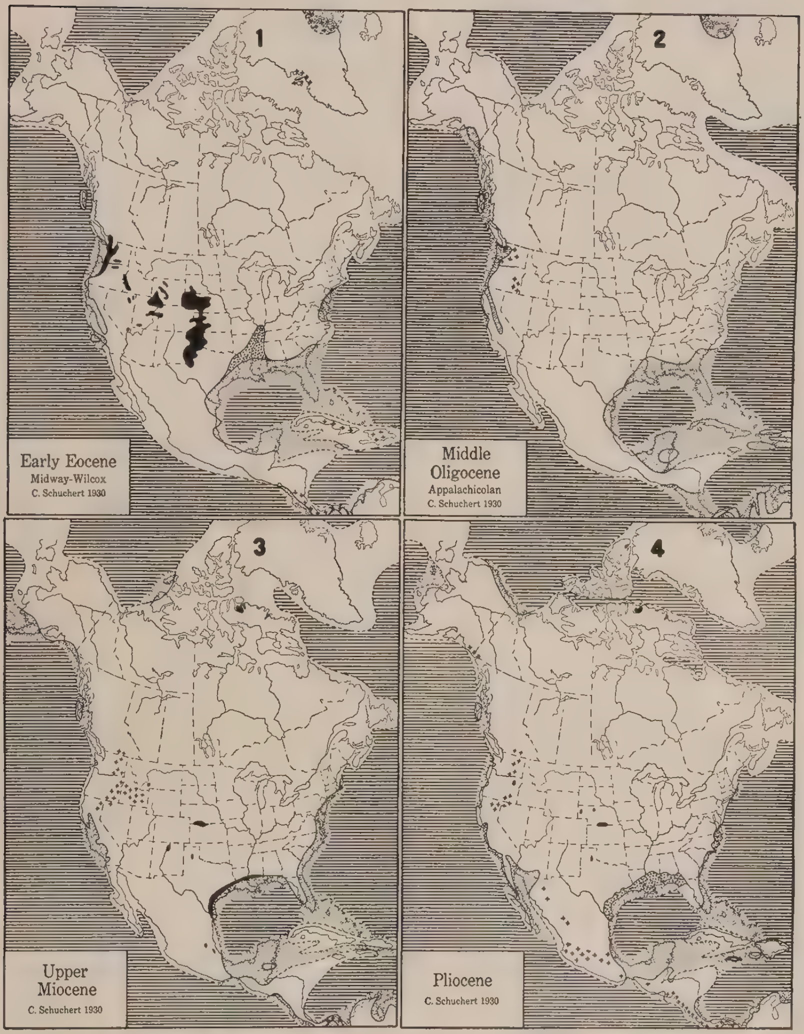


PLATE 31. — Paleogeography of Cenozoic time.

Epeiric and shelf seas dotted; oceans ruled. Fresh-water deposits with land life in solid black; in Map 1 these areas embrace all Cenozoic time. In Map 4 the large dots show the area of brackish- and fresh-water formations. Volcanic regions indicated by crosses.

Note that all geosynclines are gone except in Maps 1 and 2, where there are remnants of the Pacific one in the Great Valley of California. Also note the final closure of the Panama portal and the opening of the Tehuantepec one of Mexico.

Greenland and Norway, and the cooling temperature brought about the greatest change seen in the marine molluscs of the Cenozoic.

Marine Pliocene strata are of very limited and occasional development, occurring in North Carolina and southward and westward into Florida. Some time in this epoch the eastern border of the continent came above the water to stay.

All of the Cenozoic strata of the Atlantic border dip toward the ocean, since they were laid down on a gently sloping coastal plain that periodically rose on the west.

Gulf Border. — The Cenozoic formations of the Gulf border are more widely spread. The Gulf of Mexico, as said in Chapter XVII, reached its maximum extent in Late Cretaceous and Early Cenozoic time, and its present great depth (12,000 feet) probably after the Miocene. It was this subsidence that in all probability brought about the concentration of petroleum on the Gulf coast, of which more will be said presently. The Mississippi embayment still extended far to the north, with the apex of the delta at Cairo, Illinois, in the Eocene, and retreating to middle Alabama in the early Oligocene; from Oligocene time onward the fresh waters continued increasingly to make their influence felt, not only affecting the sedimentation of the time but also preventing the intermigration of the shallow-water marine life to the east and west of the river.

From Cape Hatteras southward and westward (see Pl. 31) the Gulf seas left a long Cenozoic record, best for the older rocks in Alabama and Mississippi and for the younger ones in Florida. The maximum thicknesses are around 2000 feet. In the north, it is a variable series of sands, greensands, and marls, with some lignite; in Florida the sands are greatly reduced in quantity and we find limestones and marls, indicating low land and quiet and warm waters.

Around the Mississippi embayment, as would be expected in a large delta, there is a mixture of fresh- and brackish-water sands and clays, with beds of lignite made by the plants accumulating in the swamps.

Westward from the river, the Gulf waters brought marine, brackish, and swamp deposits of the usual sands, clays, greensands, and lignites, and of various Cenozoic epochs, into Louisiana, Texas, and northern Mexico. This region is, however, much faulted, and locally folded, due to earth pressures resulting from the subsidence of the Gulf. In consequence the petroleum has gathered into localized pools of various ages in the Lower and Upper Cretaceous and Cenozoic formations, which have yielded enormous quantities of petroleum all the way from Arkansas and Louisiana to Tampico in Mexico.

An interesting feature of the oil fields in Louisiana and Texas is the " salt domes," a mile or so in diameter, on the flanks of which gas and petroleum often occur. These domes, or plugs, consisting in the main of fairly pure table salt capped by other salts or by fragmental limestones, have been pushed up through arches resulting from pressures set up by the subsidence of the Gulf; some of them have come up through the marine coastal Cenozoic deposits from depths of at least 5000 feet. In the salt domes the oil comes mainly from Miocene and Oligocene strata, and single domes have furnished as much as 200,000 to 300,000 barrels per acre of land. The salt appears to be of Lower Cretaceous age.

All of the marine Cenozoic strata of the Gulf border dip toward the Gulf, due to the rising of the land toward the interior after their deposition. This rising of the dry land continued all through Cenozoic time, and in the late Pliocene the whole Mississippi Valley was raised even higher than its present elevation of several hundred feet above the sea. The Cenozoic deposits of the Gulf and Atlantic borders are in the main still unconsolidated and soft, being of comparatively recent deposition and having as yet been involved in no fold-mountain disturbance.

Central America and the Antilles. — The Mesozoic and Cenozoic history of the Antillean regions forms one of the most interesting bits of regional geology. This part of the Earth's crust has been a very unstable one since at least Late Jurassic time, a fact to which its many active volcanoes, past and present, bear eloquent witness. As a result, the islands of the Antillean archipelago have been united, separated, and reunited, and the seas have repeatedly flowed across the Panama region, and at least once over that of Tehuantepec, alternately severing and welding the Americas. The geography is in detail too intricate to describe here. The region shared in the general subsidence of the Gulf of Mexico during Cretaceous and Cenozoic times, and in the mountain making of the Late Mesozoic, when the highlands of Honduras probably extended unbroken across to Jamaica, Haiti, and Porto Rico. These various positive and negative movements constantly altered the Cenozoic geography of the Greater Antilles. Beginning with the Miocene, these islands began to be more emergent in general, while the Caribbean was down-faulted more and more to its present great depths. Florida first made its appearance in Oligocene time as an island, and in the Miocene as a peninsula. Northern South America, on the contrary, was widely and deeply under the sea during most of Cenozoic time, and only began emerging with the Pliocene. The island of Barbados, once a part of South America, sank in the Miocene to 10,000 feet beneath sea-level, and in the Pliocene was again dry land. As elsewhere, the Pliocene was almost everywhere in this region a time of high and wide emergence, but during the epoch the Caribbean to the north and south of Jamaica underwent tremendous fracturing and faulting, resulting in such submarine troughs as the Bartlett deep, which goes down to 19,000 feet. Some of this changing Antillean geography is shown on Plate 31.

Pacific Border. — On the western side of the continent, the Cenozoic history differs markedly from that of the Atlantic and the Gulf, in that it is complicated by block faulting and mountain making, the Pacific coast throughout Cenozoic time being in a state of crustal instability. Moreover, the highlands here lie much closer to the coast than the eastern ones (Appalachians), so that the actual marginal overlaps are very restricted. On the other hand, the Pacific waters found entrance through the mountains into certain areas where weaknesses of the crust had given rise to structural valleys that were persistent regions of depression. Such were the Puget Sound area (much larger than the present sound), the Great Valley of California, and the Gulf of Lower California. From the highlands re-elevated in the Laramide Revolution came great streams of rock detritals that at times never reached the seas but were spread as continental deposits, and at other times were buried under the seas in the same areas. Add to this thousands of feet of lavas poured out from volcanoes, symptomatic of the crustal unrest, and it becomes evident that West coast Cenozoic history is far from being as uneventful as the simple annals of the Cenozoic East.

During the Eocene, practically all of the coast north of California was dry land, and seemingly with comparatively low relief except for steep mountains in southern Oregon and northeastern California. Over the low lands the transgressing seas ebbed and flowed in a somewhat desultory fashion. The Puget Sound area was an estuary, bordered by marshes. In this region, 125 coal beds now alternate with fresh-water and brackish-water deposits to make up a thickness of more than 10,000 feet; evidently here was an area that subsided gradually as it was filled with sediments. Elsewhere along the coast local basins went over at times into lignite-making swamps. This record of alternating marine and fresh-water deposits is made even more complicated and difficult to interpret by the volcanism that marked the lingering effects of the Laramide Revolution, volcanoes pouring out great floods of lavas over western Washington, northwestern Oregon, and California. The record in the Golden State is rather more dominantly marine, the strata aggregating approximately 9000 feet (Eaton).

The Oligocene seas were much more limited, and their record less well established. Deposits of this age aggregate nearly 15,000 feet in the Cape Flattery region of Washington, and are mainly marine; in California, they reach 4000 feet, one of the best known sections being that

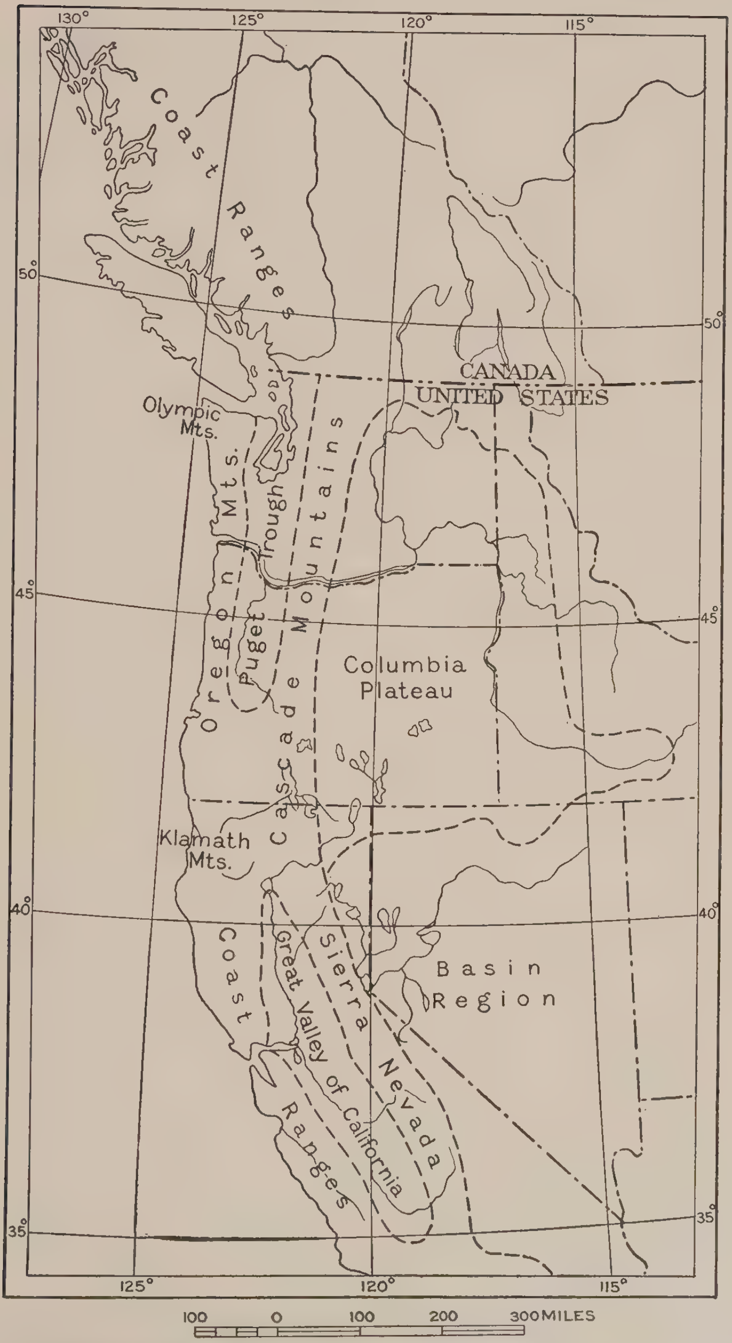


FIG. 117. — Main structural elements of the Pacific coast region. Modified from Tolman.

of the Santa Cruz Mountains south of San Francisco. The volcanic activity was insignificant as compared with that of the Eocene, and California had none at all. In general, the Oligocene was a time of erosion and peneplanation.

With the Miocene, Californian history takes on more interest and importance. The early Miocene seas pushed well into the state and laid down one of her most valuable formations from the economic point of view — the Monterey, which includes many thousands of feet of rock largely composed of the remains of those beautiful but tiny sea plants known as diatoms, each one yielding its quota of organic matter to help make the beds one of the principal sources of California oil. The Miocene strata of Washington, although at least 5000 feet thick, are not petroliferous. The Puget Sound area may have been land, since it has no proved Miocene strata.

Between the early and the late Miocene there is a great unconformity, marked in all three of the Coast states. This interruption in marine record is due to the outbreak of crustal disturbances, which altered geologic and geographic conditions quite generally. Highlands were made in eastern Washington and Oregon, and the Coast Range of California was re-elevated. The faulting consequent upon this orogeny developed the great San Andreas rift of California, which extends for 600 miles southeast into the Mohave Desert and was a line of weakness along which occurred the San Francisco earthquake of 1906. Volcanic eruptions accompanied the going up of the mountains, and into the Cascade Mountains of northern Washington was intruded a great granitic batholith.

The effects of this diastrophism on the existing strata are only too apparent. For example, in the Seattle area 12,000 feet of Eocene and Oligocene beds have been tilted until they stand on end, and many of the early coastal Cenozoic strata have locally undergone strong metamorphism. In general, the rocks are hardened and compacted, in contrast to the soft and unconsolidated condition prevailing in those of the East; a specific example is the Eocene coal beds of Puget Sound, which are hard bituminous and locally even anthracite, whereas those of equivalent age in Mississippi are of the grade of lignite.

Following the middle Miocene diastrophism, the seas came back into the coast areas of California, and also spread for the first time from Queen Charlotte north along the coast of Alaska and across the Alaskan Peninsula; the maximum thickness of deposits is in central and southern California.

The Pliocene is best known in California, where in Ventura County it is said to be 15,000 feet thick, though some Pleistocene is probably included in this figure. Pliocene rocks are also widespread in Lower California. Near Santa Barbara the Pliocene is tilted and overridden by Eocene strata, and both series were greatly eroded in Pleistocene and Recent time. The whole of the Cenozoic in Ventura County may exceed 30,000 feet in thickness.

The Alaskan Range may have been folded for the first time at the close of the Jurassic, but its maximum of height came with the early Eocene, along with volcanism. In the late Pliocene these mountains were bodily uplifted and have since been eroded into their present forms.

It is not yet clear to what extent during the Cenozoic Alaska was united with Siberia, though it seems that the ocean did not invade the Behring Strait region until late in the Pliocene. Since then the Behring bridge has been crossed by the sea at different times.

A marked feature in the Cenozoic history of the west coast is the persistence of the Great Valley of California, that long, narrow synclinal area developing after the making of the Sierra Nevada at the close of Jurassic time (see Fig. 117). The Cenozoic seas found this cul-de-sac as easy of access as did those of the Mesozoic, and since it continued to subside as it filled, it presents now some of the maximum thicknesses of Cenozoic beds on the coast. The present Golden Gate represents the entrance to this very ancient valley.

Cenozoic Continental Deposits

In Eocene time there were intermontane basins among the newly formed Laramide mountains not unlike the present " parks " of Colorado. Several of these suffered downwarping even while the mountains were still rising, and as a result they tended to trap the sediments brought down from the ranges. Some of these mountain-rimmed basins became large shallow lakes (Green River), but most of them had through-flowing streams and remained forested areas. These basins — Bighorn, Wasatch, Bridger, and Wind River of Wyoming, Uinta of Utah, San Juan of New Mexico — were gradually filled up by alluvial and volcanic deposits of great thickness and hence they give us a record of early Cenozoic land history second in interest to none, and have furnished famous treasure trove to the " bone hunter."

The structure of these Eocene basins is still largely preserved and a map of the Rocky Mountain region in the Cenozoic enables us to restore in imagination its ranges and parks (see Fig. 118).

As the warping gradually died out, the Eocene basins were silted full and the Oligocene streams, flowing at grade across them, carried their burden further east and laid it down in Wyoming, Montana,

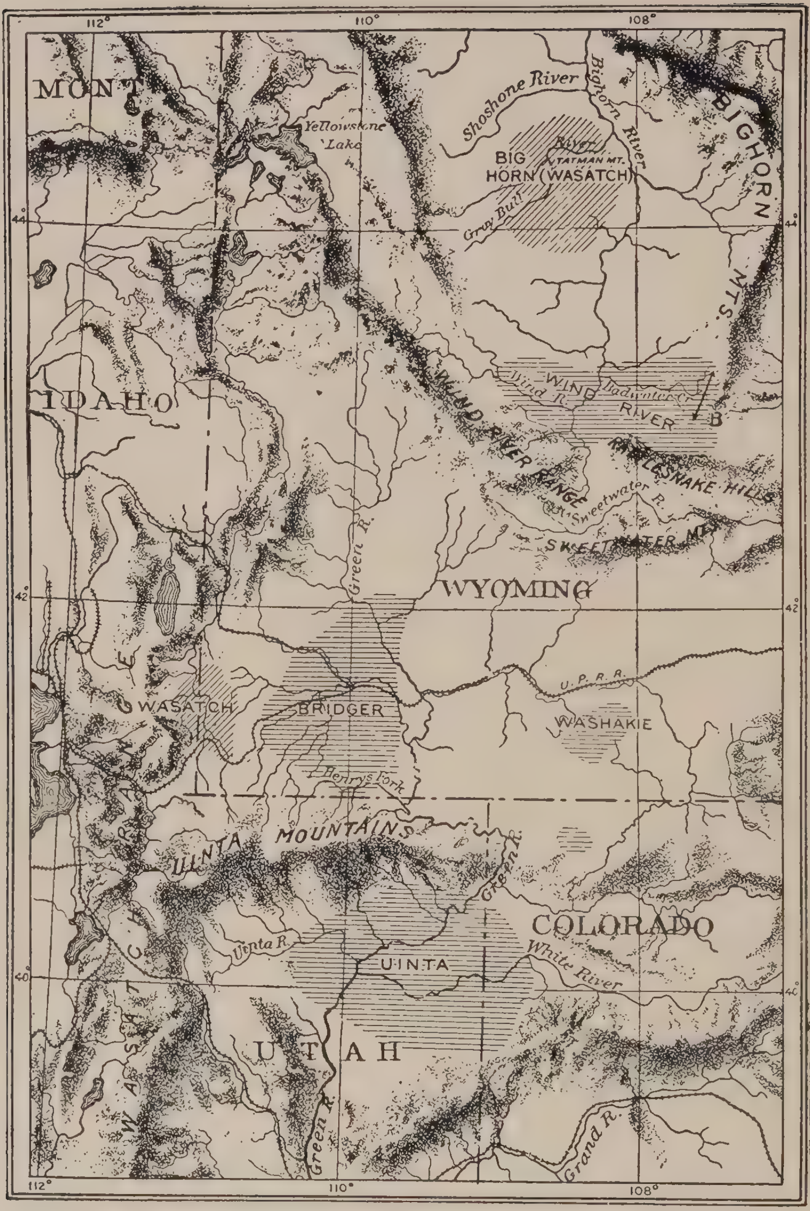


FIG. 118. — Eocene sedimentary basins in the Rocky Mountain region, from which has come an unsurpassed record of the mammalian life of that time. From Osborn.

Colorado, Nebraska, and the Dakotas. Such flood-plain accumulations afford excellent conditions for the accidental preserval of animal remains, and these particular beds, weathering out under the present arid climates into the picturesque "badlands," have revealed the most interesting known record of mammalian evolution, the remains of one organic dynasty after another, whose histories have attracted the attention of paleontologists the world over (Fig. 119). In Oregon, a small intermontane basin, the John Day, filled up with 3000 to 4000 feet of sediments, dominantly of volcanic ash, and also buried a rich mammalian fauna.

About the close of the Oligocene, there was a broad regional uplift affecting the whole Cordilleran region, and rejuvenating the streams in the Rocky Mountains. As a consequence, the deposits of the Miocene, again with a wealth of mammalian remains, not only overlie those of the Oligocene but spread beyond them eastward as well as southward into Texas. The thin Pliocene beds lie in regions scattered as widely as Oregon, Texas, and Kansas, but are of limited extent and often difficult to distinguish from those of the late Miocene.

The widely dispersed accumulations of Cenozoic fresh-water and wind-blown deposits of the High Plains region were derived, as we have seen, from the newly risen Rocky Mountains. As a rule, they are river flood-plain accumulations laid down under more or less dry climates: sandstones, sandy shales, and local conglomerates. Volcanic ash is widely distributed in the formations of the older Cenozoic, derived from the volcanoes to the west that continued active long after the Laramide Revolution; these ash beds were often reworked by water and wind. The thickness of Cenozoic strata at any one place varies from a few hundred to several thousand feet, but if all the thickest local deposits are combined the total sedimentation of this era in the High Plains area attains well over 20,000 feet.

It was formerly thought that these Cenozoic fresh-water strata had in the main been laid down in lakes of vast extent. During the past thirty years, however, it has been shown that in the main they are the materials of rivers originating in the mountains and meandering and unloading over great flood plains. The greatest exceptions were two large and very shallow lakes, one in Wyoming and one in Utah-Colorado, which at times were without outlets. In these lakes was gathered the Green River formation, averaging 2000 feet thick, noteworthy because of its high petroleum content in oil shales. This petroleum results from the abundant organic débris that formed in the lakes when they were without outlets and therefore became somewhat saline. From the Green River beds have been described thirty-five fishes, among

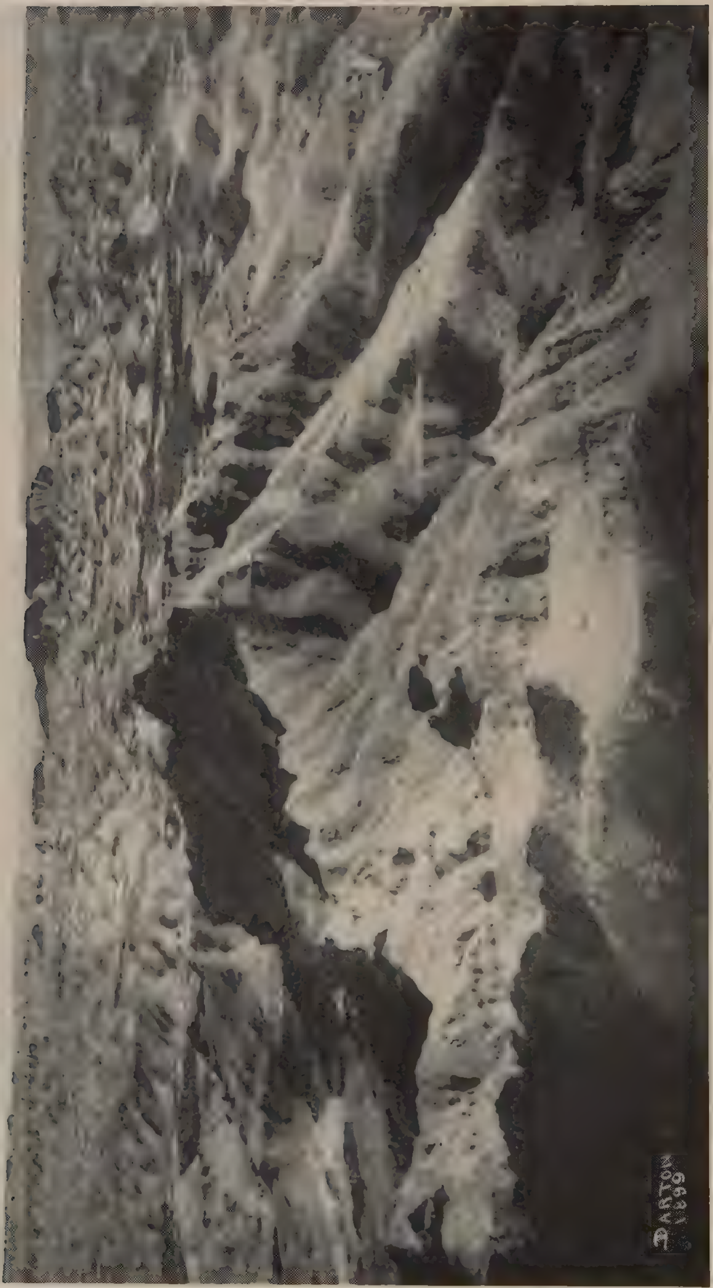


FIG. 119. — The Big Badlands. In these rocks, carved into fantastic shapes by wind and water, lies the most interesting known record of mammalian evolution during Oligocene and Miocene times. U. S. Geol. Surv.

which are eight kinds that are clearly of the sea, and got into the lake to spawn by migrating up some unknown river. One of them is a sting-ray.

The Great Basin in the Cenozoic

The Great Basin province, occupying all of Nevada and the adjacent parts of Utah and California, is now devoid of exterior drainage. This vast desert area was originally deformed at the close of the Jurassic during the Nevadian Revolution, all the way from the floor of the Pacific Ocean east to the Wasatch Mountains of Utah; as the crustal movement was toward the east, the most intense deformation and metamorphism are in the west. Shortly after the folding, most of the area was intruded by vast granitic magmas, which have risen highest in the Sierra Nevada — a series of intrusions on so large a scale as to be reminiscent of the much older Laurentian and Algoman ones of the Canadian Shield.

Since the Nevadian Revolution, the Great Basin area has not been refolded, and by early Cenozoic time the mountains were peneplained across. Probably at the close of the Pliocene, when the whole Cordilleran region, including the Great Plains, was bowed up all the way from the Arctic to Tehuantepec, the Sierra Nevada was re-faulted along its eastern side; and the whole of the plateau, too broad to maintain its uparched position, broke up into the block mountains seen to-day in the Basin Ranges, those more or less parallel north-south ridges that form so marked a feature of western Utah and Nevada. Even to-day this region has not attained equilibrium, since it has fresh fault scarps 40 to 50 feet high (Carson Valley, Mono Lake, Owens Valley) on some of which there has been movement in recent years, accompanied by violent earthquakes. Since at least Pliocene time the Great Basin has been the area of the Great American Desert. (Figs. 120, 121.)

Colorado Plateau and Grand Canyon

Between the Great Basin in the west and the southern ranges of the Rockies on the east lies the highly elevated Colorado Plateau, covering much of Colorado, Utah, Arizona, and New Mexico. The striking feature of this plateau, framed as it is by mountains, is its horizontal strata of Cenozoic, Mesozoic, and Paleozoic ages, the last of which rest with profound unconformity on the Pre-Cambrian. Nowhere south of the Uinta Mountains (Utah) have these rocks been folded since Pre-Cambrian time, and they represent " a large island of persistent stability in a sea of mountains " (Lawson). This plateau region has risen several times since the Laramide Revolution at the end of the Cretaceous, so that from being the lowest part of the interior continental basin, it has become one of the highest parts of the Cordilleran arch. Its present high altitude was attained in the Pliocene. The amount of elevation during late Cretaceous and Cenozoic times has been something like 20,000 feet, about 12,000 feet of which has been carried away by erosion, leaving still 8000 feet of general elevation (Lawson). At El Tovar on the southern Canyon rim this plateau surface stands at 7000 feet, and on the north side the Kaibab Plateau is 8000 feet above the sea. The upper part of the Grand Canyon, 10 to 15 miles wide and revealing about 4000 feet of Paleozoic strata, is the result of erosion during the Pliocene, while the much narrower inner gorge in the Pre-Cambrian rocks, varying from 0 to 2000 in depth, is the work of Pleistocene time. This mile-deep gorge shows the finest exposures anywhere of the succession of Paleozoic sea bottoms. These in turn rest upon the oldest of the Earth's rocks, which had undergone two periods of mountain making and peneplanation before the coming in of the Paleozoic seas. Such is the evidence of eternal change.

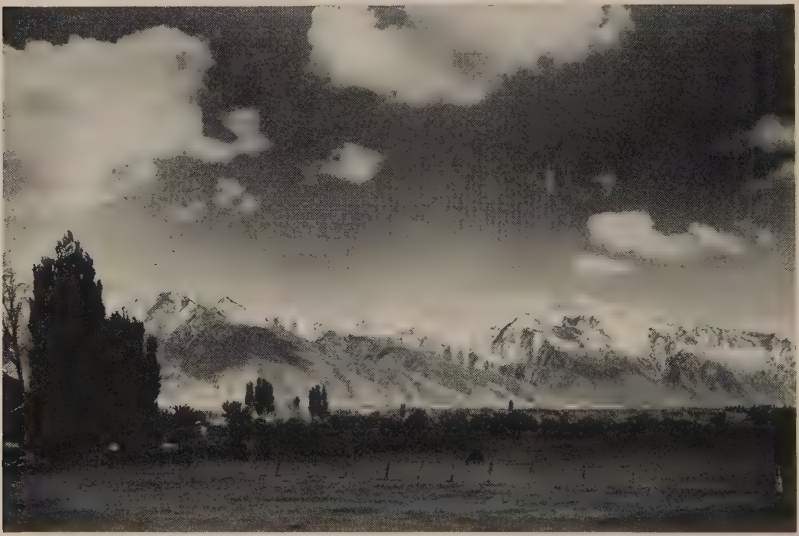


FIG. 120. — The east wall of the Great Basin: the Wasatch Range near Salt Lake City. Photograph by Shipler.

CASCADIAN REVOLUTION

In the chapter on the Cretaceous it was stated that the Mesozoic era in North America was closed by the Laramide Revolution, when the Laramide mountains (including the Rocky Mountains) were folded and thrust toward the east (see page 235). Eruptions, mainly of an explosive character, continued, though with diminishing force, throughout Eocene and Oligocene time, but the Earth-shell remained fairly stable, enabling the atmospheric forces to reduce greatly the high elevations of these mountains.

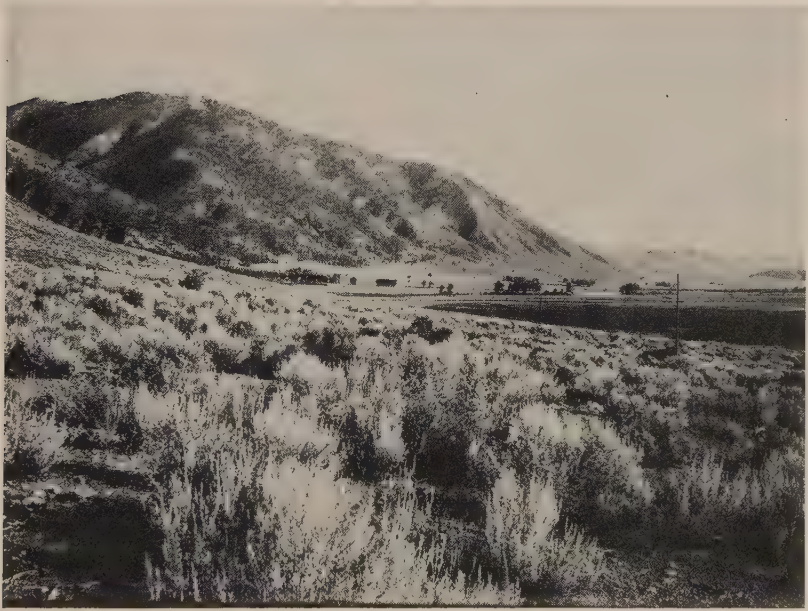


FIG. 121. — The Sierra Nevada fault-scarp, forming the western wall of the Great Basin. Photographed by G. D. Louderback near Genoa Peak, Nevada, where the scarp is approximately 4000 feet high.

The crustal uplifts which attained their culmination at the close of the Cenozoic era, and which have been called the Cascadian Revolution, had their beginning as early as middle Miocene time, when the Pacific States were again in the throes of mountain making, and igneous eruptions became active, with the formation of highlands in eastern Washington and Oregon. In the states of Idaho, Washington, and Oregon there is a lava plateau of Miocene age fully 200,000 square miles in area and in places over 4000 feet in depth; the lavas welled out of fissures. To-day the Columbia and Snake rivers flow in deep canyons cut through this vast lava plateau. At the same time, as we have seen, came the second period of elevation of the Coast Range of California, and the making of the San Andreas rift.

At the close of the Pliocene or early in the Pleistocene, the Sierra

Nevada was elevated bodily from 5000 to 7000 feet and it is still going up. These mountains form a crust block about 600 miles long and 75 miles wide, greatly elevated on the eastern side, where there is a great fault with from 3 to 4 miles of vertical displacement.

During the late Miocene and early Pliocene, decided folding and faulting with volcanic activity also occurred in the Isthmus of Tehuantepec of southern Mexico, in Central America, and apparently throughout the Antillean islands. Finally, it may be said that especially during the Miocene, and less in the Pliocene, the entire area of the overlaps of the Pacific Ocean in North America (see Fig. 122) was being elevated, folded, faulted, and thrust into the Pacific System of mountains. During the later Pliocene, the entire Rocky Mountains, and especially the plateau region of the Colorado River, were further vertically elevated several thousand feet. In Pleistocene time there were at least eight prominent volcanoes ranging from Mt. Shasta of California north into British Columbia.

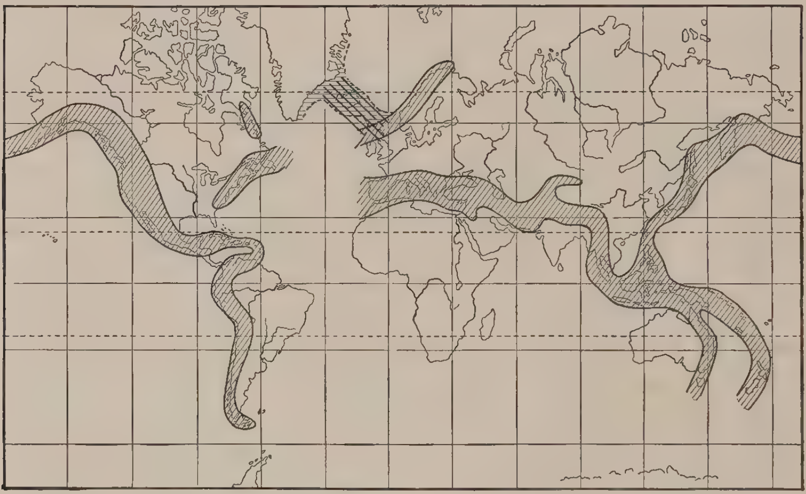


Fig. 122. — Areas of dominant folding and uplift (oblique shading) during the Cenozoic. Horizontal shading, the fractured and down-sinking area of the northern Holarctic continent (Eria); northwest-southeast lines, the general direction of fractures and dikes.

Eastern North America was also elevated in Pliocene time, but how much is not yet determined, and the entire Mississippi valley was raised several hundred feet, or higher than its present elevation.

The Cenozoic was also a time of mountain making in countries outside of the North American continent. In South America toward the close of the Cretaceous the Andes had been elevated, folded, and thrust eastward throughout the length of the continent (4500 miles), and during most of Cenozoic time an extensive peneplain was being developed in the Central Andes. Vertical uplift began in later Cenozoic time, elevating this peneplain from 3000 to 7000 feet. This was in turn eroded to mature slopes and then reëlevated in Pliocene and early Pleistocene time, so that now the deeply dissected erosion surface of the old peneplain stands at an average elevation of 12,000 feet, though locally it varies between 6000 and 15,000 feet. This plain is best seen in the Altiplanicie, the high plains of Bolivia. Upon it in the east rest immense lava flows and lofty volcanic cones, some of which attain a height of 21,000 feet above the sea.

Eastern Greenland and the region eastward across Spitzbergen, Norway, Sweden, and Finland (Fennoscandia) were subject to great block faultings and warpings, seemingly in late Miocene time. This was the time when the old land of Eria was separated from Baltica (Fig. 122). Periodically, but more especially during the late Eocene and Oligocene, lava (the Thulean basalts) flowed widely through fissures over all the lands bordering the Atlantic in the northeast. The foundering of the crust where the Norwegian sea now is, permitted the triumphant spread of the Atlantic into the Arctic Ocean.

In Europe, the majestic Alps are mute evidence of the great unrest of the Earth's crust during the Cenozoic. The movement here began in the west with the Pyrenees of Spain, the Rif Mountains of Morocco, and the Apennines of northern Italy. Then the entire Alpine system of western Europe began to rise bodily, and this elevation was completed in the late Pliocene-early Pleistocene, when these mountains stood at their highest.

The Himalayas of India, as early as the Middle Cretaceous, began blotting out in Asia much of the former extent of Tethys. At the close of the Eocene, however, all of the Tethyian area of the Himalayas and Burma began to fold, giving rise to mountains of considerable altitude in many regions, and yet not extensive enough to shut out the sea. During the Oligocene, Tethys, even though shallow, still preserved its continuity, but toward the close of the middle Miocene, the second and more marked phase of folding began, changing it into a series of disconnected but subsiding basins. Finally, in the Pliocene, came the third and greatest upheaval, when the Himalayas, the loftiest mountains of the Earth, were completed. This uplift affected the land to the north for 1400 miles into Tibet and Mongolia.

The closing revolution of the Cenozoic era was a critical period in the history of the Earth, and as it culminated in the Pleistocene glacial climate, the conditions were all the more hazardous for the organisms that inhabited the polar and temperate parts of the Earth. The warmer regions of the globe were the asylums that repeopled the northern lands, but man, arising in either Asia or Africa even before the Pleistocene, advanced during the Glacial Period from the savage to the civilized state under the influence of cooler and even cold climates. We are now living in a time of rugged lands, obliteration of ancient peneplains, cold polar climates, and marked temperature belts.

CENOZOIC CLIMATE

In the area of the Rocky Mountains, the climate in early Upper Cretaceous time was even warmer than at present along the Gulf of Mexico. Toward the close of the period, the temperature was cooler, with distinct winters like those of the present Dismal Swamp of Virginia; and during earliest Eocene time the climate was cool to cold, and semi-arid.

Beds of tillites ranging in thickness from 80 to 100 feet were discovered in 1913 at a number of localities in the San Juan Mountains of Colorado, fulfilling a theoretic prediction. These Ridgway tillites unconformably overlie the Cretaceous and are covered by Eocene tuffs, indicating a possible early Eocene age. It is to be expected that other areas of these tills will be found. In the Gulf Coast area of Mexico and the lowlands of the United States, however, the Eocene climate was almost subtropical, and the Puget Sound region had palms and figs. Toward the close of the Eocene, the floras of even arctic lands show the return of mild climates, as mild as that of the present Gulf States. Along the Yukon then lived warm-climate cycads, magnolias, and delicate ferns.

It has long been recognized that during all of the Oligocene there were world-wide genial climates. Furthermore, up to the close of the Oligocene the climates of North America were moist and the lands lay near sea-level. With the Miocene, however, the lands in many parts of the world began to rise into mountains, and gradually the climates became cooler and drier. More or less of desert climates developed in the Cordilleran areas of North America and have prevailed there ever since. In the late Miocene, parts of Eria foundered (see Fig. 122), separating Greenland from Norway and Scotland, and cooler waters spread all along the Atlantic shores of North America. The climate continued to grow cooler, and in the Pleistocene occurred one of the three most marked glacial climates known to geologists, described in Chapter XX.

Life of the Cenozoic

In the world of *marine invertebrates*, there was a great change in the Cenozoic, for although many genera of the Mesozoic continue into the Eocene, none of the species do. The Eocene marine faunas show, however, but 5 per cent of living species.

In general, the seas of the Cenozoic were characterized by bivalved molluscs, which were then at the height of their specific differentiation; in fact, so abundant are these shells in the rocks of the Paris basin, and so wonderfully preserved, that they formed the basis for the differentiation of the Cenozoic into epochs. Oysters attained their climax of development in the Miocene of California, where the giants had a length of 13 inches and a depth of 6 inches. Of the grand array of Mesozoic ammonites, however, not a single one passed over into Cenozoic time. Of special note toward the end of the Eocene were certain large Foraminifera, known as nummulites because of their resemblance to a small Roman coin (*nummulus*), which swarmed in the warm waters of the mediterranean Tethys. The limestones made by these little animals are in places several thousands of feet thick, and furnished the building stone for the pyramids of Egypt.

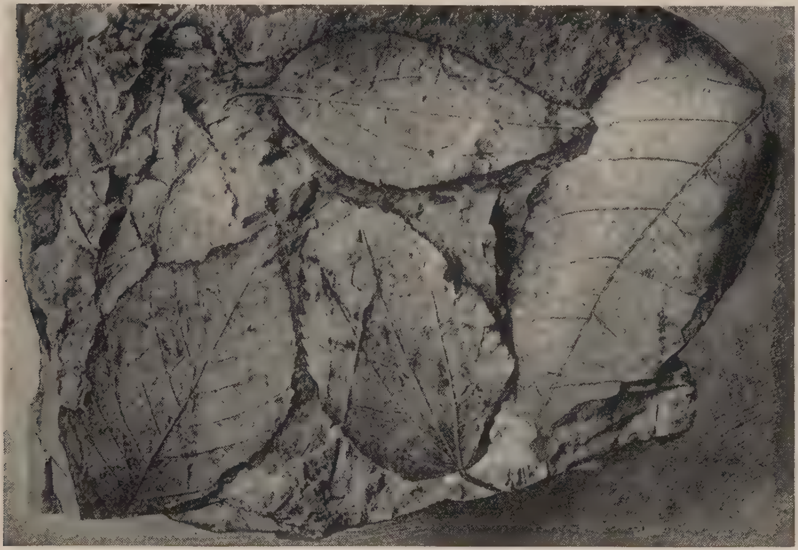


Fig. 123. — Eocene leaves from the Puget Sound Region. At the top, a pepper; left to right below, an alder, a red-root, and a walnut. From Knowlton's *Plants of the Past*, by courtesy of the Princeton University Press. Original in U. S. National Museum.

The *land floras* of the Cenozoic had arisen in the Cretaceous, and the woody trees and bushes were much like those of the present (Fig. 123). The palms were especially abundant in the first half of Cenozoic time, and throughout the era the sequoias were of world-wide distribution. To-day but two species of the latter are living, in isolated areas in California, where some of the individual trees are known to have attained an age of upward of 3000 years. Trunks of Pliocene trees are still to be seen standing upright in Yellowstone Park, where several forests were buried under the ash of a series of volcanic eruptions, and are now weathering out of the rocky hillsides (Fig. 124).

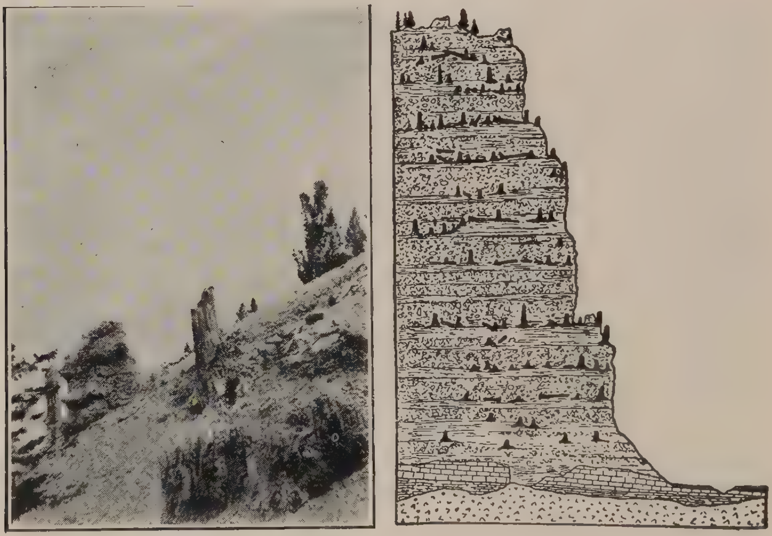


FIG. 124. — Left, Miocene tree trunks in Yellowstone Park; right, a 2000-foot section of Amethyst Mountain in the Park, showing how at least seventeen forests were successively killed and buried by volcanic ash. After American Museum of Natural History and W. H. Holmes, from Curtis and Guthrie's *Textbook of General Zoology*. Reprinted by permission of John Wiley and Sons.

More than 6000 kinds of Cenozoic *insects* are known, and the fullness of insect life in that era may be said to have been attained in the Miocene. Among the famous localities for the preserval of these fragile creatures are the fine volcanic deposits of Miocene Lake Florissant, in Colorado, which have yielded more than 1000 species, and the Lower Oligocene ambers — the hardened resin of pine trees — of the Baltic region, which preserve some 2000 species of them in the most delicate detail, together with crustaceans, spiders, and plants.

The Mesozoic was the *Age of Reptiles*, the Cenozoic the *Age of*

Mammals. The wonderful reptile development of the Mesozoic was nearly all gone in the earliest Eocene, and at no time in the Cenozoic or since have these animals played a conspicuous rôle. Their places were taken by the mammals, which were present in greatest variety and number and dominated the life not only of the lands but of the seas and oceans as well. In the later Eocene occurred the first mammal adaptation to an oceanic life, in the form of whalelike animals (zeuglodonts), whose fossil bones occur abundantly in parts of our Southern States, in Egypt, and in Europe. One of these, *Basilosaurus* (Fig. 125), must have been the " sea serpent " of its time, with 4 feet of head, 10 feet of body, and 40 feet of tail! In fact, the tail vertebræ are, relative to the animal's bulk, the longest known, measuring from 15 to 18 inches in length. The head was small and pointed, and just back of it was a pair of short paddles somewhat like those of the fur-seal. But even a mammal of this size met its match in the great sharks of those seas, the gaping jaws of one of which (*Carcharodon megalodon*) must have been about 6 feet across.

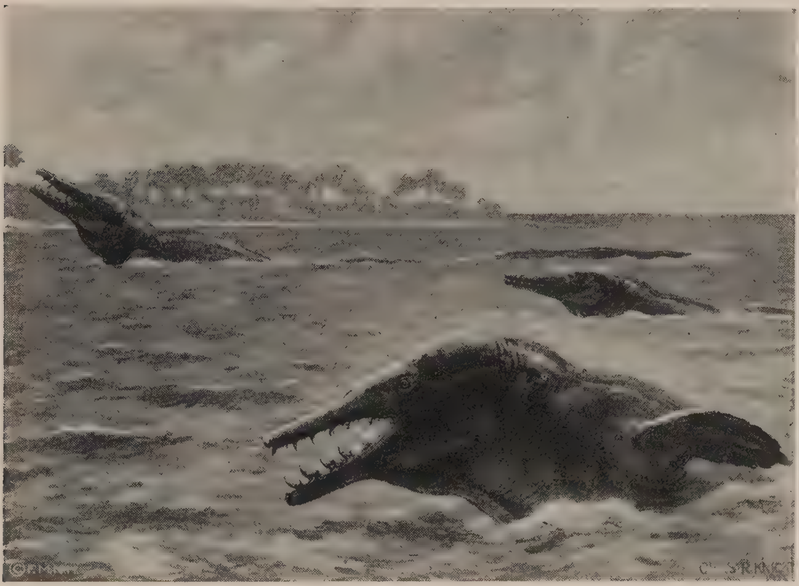


FIG. 125. — *Basilosaurus*, a primitive whale or zeuglodont, living along the coast of the South Atlantic States in Eocene time. Painted by Charles R. Knight for the Field Museum of Natural History, Chicago.

Sea-cows, also marine mammals, came in the Oligocene, and the true whales, seals, and sea-lions in the Miocene. The land mammals are discussed in the following chapter.

Nearly all the continents at some time during the Cenozoic had large ground-living ostrich-like *birds*. The tallest and heaviest of these were the moas of New Zealand, exterminated by the Maoris five or six centuries ago. There were about twenty kinds, the largest of which, *Dinornis maximus*, stood 10 feet high, 2 feet above the largest ostrich. Another closely related but smaller form was *Æpyornis* of Madagascar, a bird that laid the largest of all known eggs, 9 by 13 inches. It was the finding of these eggs by the early navigators that led to the vast exaggerations which thrill the reader with wonder and terror in the accounts of the Roc given by Sindbad the Sailor in the Arabian Nights.

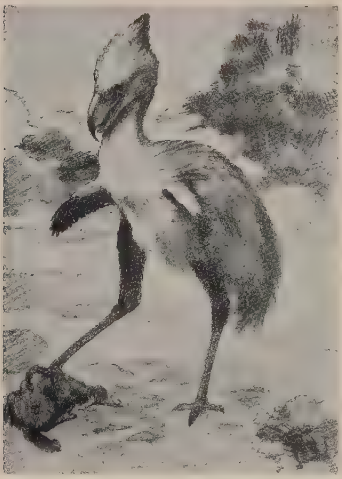


FIG. 126. — *Phororhacos*, the giant bird of the Patagonian Miocene. The skull is as large as that of the largest horse. After Knight. From Lucas' *Animals of the Past*.

Modern birds began in the Eocene, but while there must have been many kinds, not more than twenty-five species are known in North America. During early Eocene time there lived in Wyoming a gigantic running bird with only vestiges of wings, known as *Diatryma*. A specimen of this mounted in the American Museum of Natural History stands nearly 7 feet high, and shows a short but massive neck surmounted by a head as large as that of a horse; the wings, however, were small, almost aborted. In the Oligocene only six kinds of American birds have been recovered and in the Miocene only twenty-three kinds. The Pliocene has yielded ten, while the Pleistocene has fifty-one extinct species and fossil specimens of 108 living forms. This Pleistocene abundance is due to the well known cave deposits in many places, and to the tar pools of California.

The most powerful of all ground-living birds of Cenozoic time was *Phororhacos*, found in the Pampas formation of Argentina, standing 7 to 8 feet, with a skull 23 inches long, heavy, and decidedly beaked, apparently the most terrible of birds of prey. It was not at all related to the ostriches, but rather to the living herons (see Fig. 126).

CHAPTER XIX

THE EVOLUTION OF MAMMALS AND THE RISE OF MENTALITY

Mammals are the highest and most complex development among animals, just as the angiosperms are among plants, and the human being is by all odds the most intellectual of the mammals and thus of all life. The mammals arose out of advanced reptiles, and probably originated in the Late Triassic.

In the Jurassic and Early Cretaceous the history of the mammals is scattering, but during this time they developed a higher type of brain and greater activity and alertness than any other vertebrate save perhaps the bird. In the Late Cretaceous these active, bright-eyed, little animals came out of their seclusion and their history looms larger and larger all through Cenozoic time, until they culminate as a class in the Pliocene and as man in the Pleistocene. Accordingly, this chapter will be devoted to the mammals, with the reminder that the general characteristics of these animals were given in Chapter VI.

It has been estimated that there are about 20,000 kinds of known living mammals in all the world, the majority of which are small or nocturnal in habit. In 1858 some 220 kinds of North American mammals were known, and now this number has increased to about 2500.

As the longest geological record and greatest diversification of the mammals occurs in the northern hemisphere (Holarctica), it is thought that the class diversified here, probably more so in Eurasia than in North America, and thence radiated into all parts of the world. Of course, some northern stocks got into the southern continents in later Mesozoic time and were there isolated, as on Australia, where the marsupial mammals (*e.g.*, kangaroos) evolved into a great variety of forms reminiscent of the placental mammals of Holarctica. (Fig. 127.)

Mesozoic Mammals. — Remains of Mesozoic mammals are among the " smallest, the rarest, and the most fragile of fossils " (Simpson). The oldest ones occur in the Rhætic strata of Germany (4 species); this formation is usually placed at the top of the Triassic but it may actually be of Jurassic time. Four other forms are found in the Rhætic of England, but none of these have been demonstrated to be multituberculates. The two species from the Upper Triassic of Virginia, formerly supposed to be mammals, are now definitely placed among the reptiles. About

65 kinds are present in the Jurassic strata of England, America, and South Africa, and around 30 in the Cretaceous of those three countries and China.

Scant as the Mesozoic material is, it nevertheless represents, according to Simpson, at least six orders, one of which, the Multituberculata (so called from their many-cusped teeth), were the most widely distributed in time and space, beginning in the Rhætic and vanishing in the Eocene. Three other orders died out in the Jurassic, but one of them (Pantotheria) may have given rise to all the higher mammals. In the Late Cretaceous appeared the living orders of marsupials and insectivores.

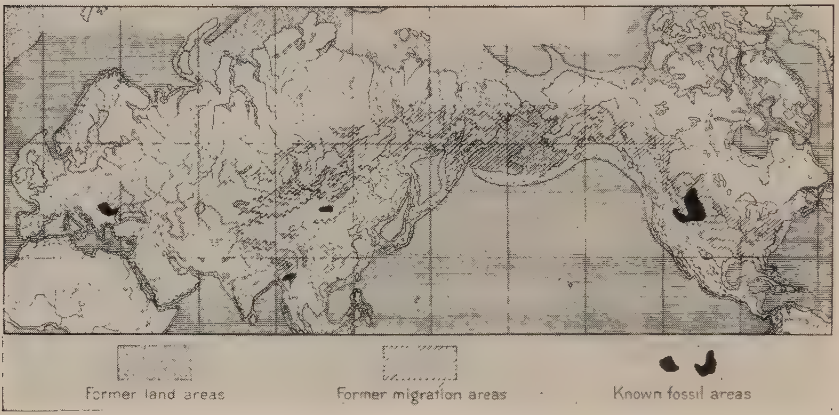


Fig. 127. — The lands comprising Holarctica, showing the migration routes of the mammals, and the local occurrences of the titanotheres (black) in early Cenozoic time. The same Siberian-Alaskan land-bridge was available for the distribution of life from early in the Paleozoic to late in the Cenozoic. From Osborn.

The Mesozoic mammals were small creatures about the size of a rat, but with a relatively large head and a long tail. One South African form, however, has a skull-length of 3.5 inches. If the skull and lower jaw of certain of these earliest mammals had been "made to order," they could not be a more perfect intermediate stage between the older cynodont reptiles and the primitive mammals. In the cynodonts the bones of the hand are also remarkably like those of the mammals. In general, it may be said that the Mesozoic mammals were most like opossums, tree shrews, and the like — tropical or at least warm temperate forest dwellers, feeding on insects, fruits, and seeds. They were a primitive generalized assemblage, out of which could develop the many later specialized groups. (Fig. 128.)

Archaic Mammals. — The archaic mammals are present in the Late

Cretaceous and Early Cenozoic — omnivorous or fruit-eating animals, dominantly placental, and small. Already highly varied, in at least six orders, none of them was as large as a sheep, and the brains were exceedingly small (see Fig. 129, of a much later archaic mammal). The archaic mammals of the early Eocene probably developed out of the insectivores in some unknown northern land, and spread thence to North America and Europe.

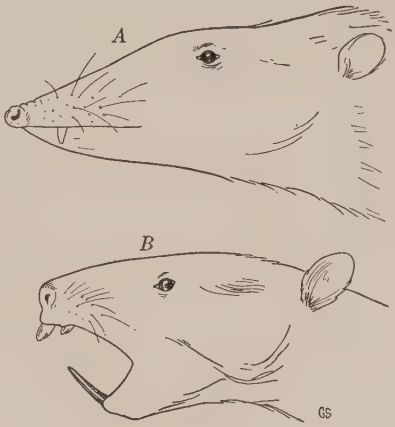


Fig. 128. — Heads of two of the Mesozoic mammals, as restored by G. G. Simpson. *A*, *Zalambdalestes* of the Cretaceous of Mongolia; *B*, the Jurassic *Ctenacodon*, known in both North America and Europe. About twice natural size. From Schuchert and LeVene's *The Earth and its Rhythms* (Appleton).

Of this archaic assemblage, the *creodonts* are perhaps the most interesting, in that they foreshadow the true carnivores, some of them being bear-like, others dog-like or otter-like, some resembling the cats or hyenas. They also persisted the longest of any of the archaic types, due probably to superior mentality.

Included also among the archaic types were the *condylarths*, primitive hoofed mammals (ungulates), similar in appearance to the creodonts but not carnivorous and possibly ancestral to all the other orders of hoofed animals. Largest of all were the hoofed *amblypods*, represented by the unwieldy *Coryphodon* (Fig. 130).

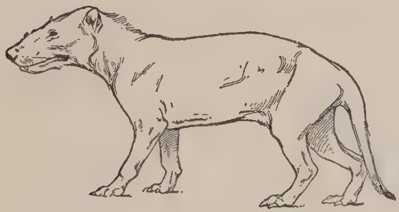


Fig. 129. — One of the last of the archaic carnivores (*Hyænodon*), of Oligocene age. These animals were the direct ancestors of all later carnivores. From Osborn's *Age of Mammals* (Macmillan).

Modern Mammals. — The archaic mammals had advanced only a little way in their specialization when they were overwhelmed by a new flood of still higher types, probably radiating also from the northern center. Some of the archaic types lasted through the Eocene, a few into the Oligocene, and then the stock died out; but of primitive mammals several still survive in the outlying regions of the Earth (marsupials, insectivores, and edentates). With the new invasion came in the first of the rodents and primates, and the odd- and even-toed hoofed mammals, in other words, the ancestors of the principal modern groups. Even these early "modern" mammals — again a generalized lot — were small creatures and not very intelligent by our present standards, but still far above the reptiles in mentality. They all had short-crowned molars, sharp cutting front teeth, the canines enlarged and pointed, and all the teeth except the molars were replaced by a second set, the permanent dentition. They had small claws on the toes and walked mostly on the flat of the foot.

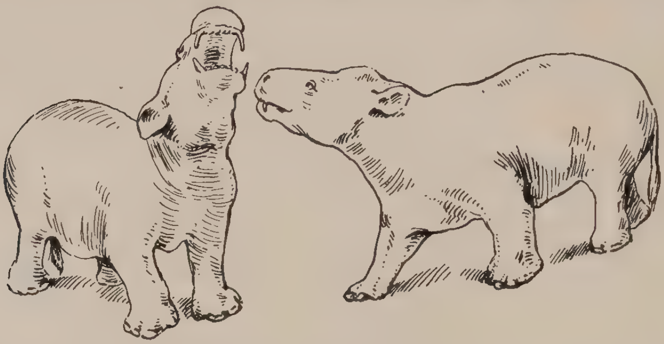


Fig. 130. — *Coryphodon*, largest of the archaic mammals. Found in twenty species in the lower Eocene of Wyoming, Colorado, and New Mexico. After Knight.

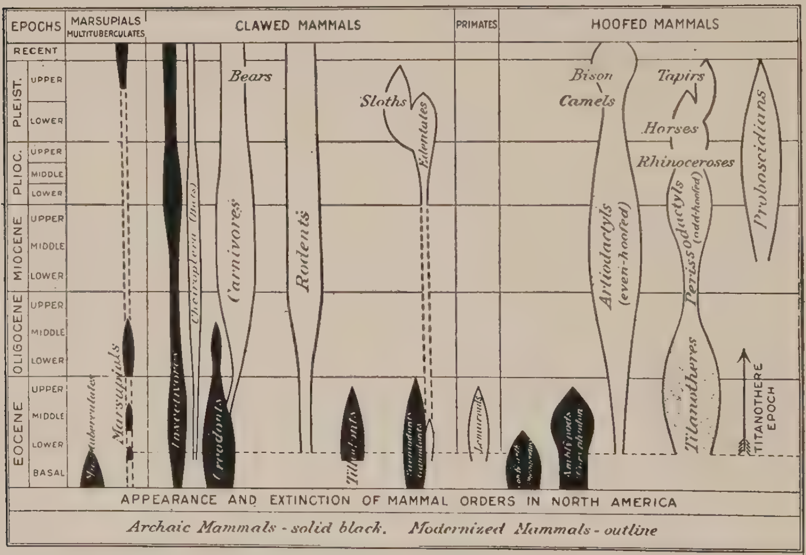
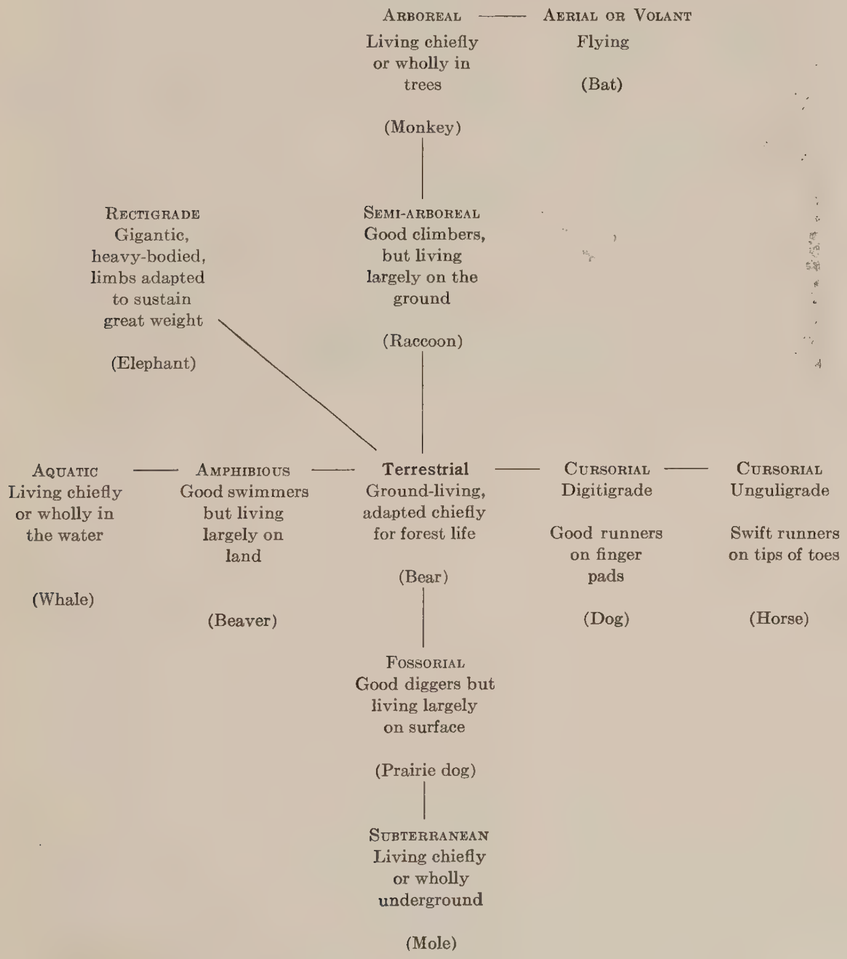


Fig. 131. — Diagram showing the life range of the various groups of archaic mammals (solid black), and of the modernized mammals (outline) that began to replace them in the later Eocene. From Osborn.

From this primitive terrestrial type the mammals specialized in every direction until they became adapted to all possible environments and the living forms are now divided into ten great branches, as follows:

- Insectivores
- Bats
- Primates
- Carnivores
- Seals
- Whales
- Hoofed animals
- Sea-cows and manatees
- Rodents
- Edentates

ADAPTIVE SPECIALIZATION IN LIMBS OF VERTEBRATES
(After Matthew)


Arboreal
Living chiefly or wholly in trees
(Monkey)
Aerial or Volant
Flying
(Bat)
Rectigrade
Gigantic, heavy-bodied, limbs adapted to sustain great weight
(Elephant)
Semi-arboreal
Good climbers, but living largely on the ground
(Raccoon)
Aquatic
Living chiefly or wholly in the water
(Whale)
Amphibious
Good swimmers but living largely on land
(Beaver)
Terrestrial
Ground-living, adapted chiefly for forest life
(Bear)
Cursorial
Digitigrade
Good runners on finger pads
(Dog)
Cursorial
Unguligrade
Swift runners on tips of toes
(Horse)
Fossorial
Good diggers but living largely on surface
(Prairie dog)
Subterranean
Living chiefly or wholly underground
(Mole)

A brief review of the various mammalian faunas of the Cenozoic follows.

Eocene Mammals. — The most striking feature of the life of early Eocene time (Wasatch-Wind River) was the appearance in considerable numbers, both in western Europe and North America, of the progressive or modernized placental mammals. Among these lower Eocene forms were diminutive horselike animals (*Eohippus*, Fig. 132), fleet-footed rhinoceroses, tapirs without a proboscis, the first ruminants and piglike forms, squirrel-like rodents, carnivores, lemurs, and monkeys; opossums (marsupials) were probably also present. It was in the main the mammalian life of a mountainous country, superior in foot and tooth structure to the indigenous archaic fauna and of a higher intelligence. In the struggle for existence the primitive mammals were consequently the losers.

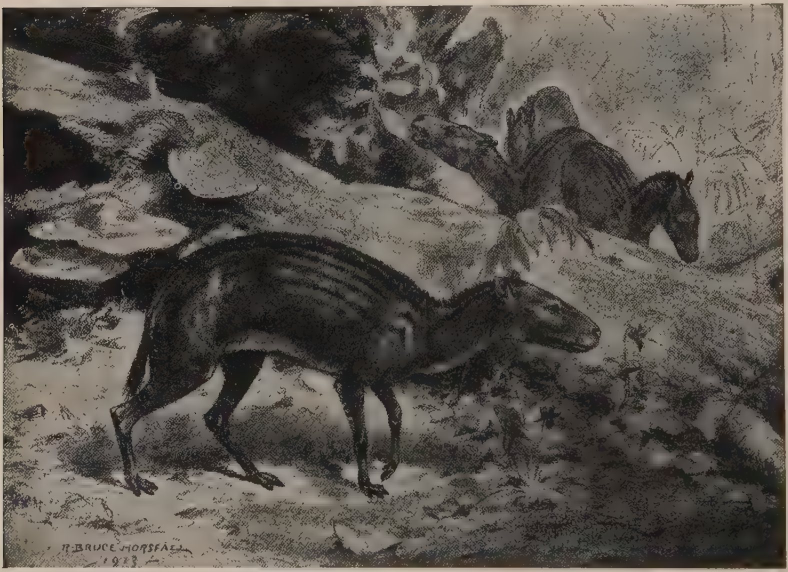


Fig. 132. — The "dawn horse" (*Eohippus*) of the lower Eocene. Restored from a skeleton in the American Museum of Natural History. From Scott's *History of Land Mammals* (Macmillan).

In the great abundance of mammals in the later Eocene there was no evidence of new migrants having come from Asia or Europe, but the fauna was dominantly that of the older Eocene with a smaller proportion of archaic types. The changes were largely toward greater size, more muscular power, and the origination of new native forms. There were many hoofed animals and all were browsers. This was again an upland or mountainous mammal assemblage, on the whole well balanced, with an equal distribution of arboreal, running, aquatic, burrowing, carnivorous, and herbivorous types.

It is now known that during Eocene and early Oligocene times in North America there lived at least sixteen successive mammal dynasties, each characterized by its own kinds. Here again we see the constant shifting of scenes, for nothing is constant in the organic world because of the ever changing environmental conditions and the struggle for existence.

Oligocene Mammals. — It was during the Oligocene that mammals for the first time took on a modern aspect, for here nearly all were progressive forms, and we begin to get representatives also of still existing families. Then in this period we get our first knowledge of the varied mammalian life of the open plains, the grazing types, indicating that the grasses were taking possession of the open country. The grasses, and especially their seeds, are highly nutritious, and they thus furnished a great stimulus to the rise and spread of the herbivorous mammals.

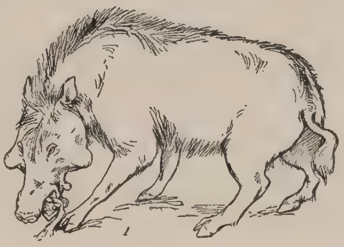


Fig. 133. — One of the giant "pigs" or entelodonts (*Archæotherium*) of the Oligocene. From Scott's *History of Land Mammals* (Macmillan).

Early in the Oligocene took place a second and more marked invasion from Europe. The interchange was considerable, yet it was not complete and the time of migration was of short duration. Europe lost its horses early in the Oligocene, but in North America there was continued evolution of the three-toed forms. The camels were also better represented, and among them were grazers, these and other hoofed mammals being present in bewildering variety. The tapirs were not common, but of rhinoceroses there were many. Rodents were likewise common, among them beavers, squirrels, pocket gophers, mice, and hares. Among the ruminants, peccaries were numerous, the entelodonts of large size (see Fig. 133), and the oreodonts, not unlike the peccaries and wild boars in appearance and size, ran in great herds (see Fig. 5). Among the carnivores, small dogs were remarkably abundant and diversified, in fact, more so than ever before or since; and both the cat stocks were represented.

Miocene Mammals. — The Miocene was the "Mammalian Golden Age" and the epoch is replete with interest because of the changes wrought in the faunas and in the floras by the alteration in climate to cooler and semiarid conditions. The later Miocene especially was characterized by an increase of grassy plains, and the mammalian teeth altered even more commonly than in the Oligocene from the browsing type to the grinding or grazing kinds (Fig. 136). There were now large numbers of horses, camels, ruminants, and rodents with high-crowned, persistently growing, grinding teeth.

The third marked migration of mammals into North America took place not only during the Miocene but during the Pliocene as well, and the migrants came from Asia by way of the Siberia-Alaska bridge. The most conspicuous among Miocene forms were the four-tusked, browsing, long-faced mastodons, the short-legged rhinoceroses, the cats, and the beavers.

Prominent among the Miocene mammals were the horses, which roamed the plains in great herds. Camels were also plentiful. Rhinoceroses were present in great variety. Peccaries abounded, and the last of the giant " pigs," the entelodonts, occurred in the lower Miocene, one of them being over 6 feet tall. Oreodonts were still present, but on the wane (see Fig. 5). The first of the true deer appeared in the lower Miocene, and in addition there were hornless deer and antlered deer-antelopes that were slender and graceful little creatures.

Among the carnivores, the dog kinds were in great variety, some small, others as large as the largest bears. Sabre-tooth tigers were plentiful though not large. There were also weasels, martens, otters, and raccoons.

Pliocene and Pleistocene Mammals. — Of Pliocene mammals in North America not much can be said, because strata of this age are scarce. The continent stood high and was undergoing elevation in the western portion, with the result that the rivers carried into the sea their loads of sand and mud.

Of mastodons there were several species; the horses, in considerable variety, were still three-toed; llamas and the tallest of giraffe-like camels continued to live; rhinoceroses with and without horns were present; sabre-tooth tigers and true cats existed, some of them as large as the lion.

Migration between North and South America took place very early in the Cenozoic, and the latter continent then became an island continent and for a long time evolved mammals peculiar to itself. Probably the most striking of these were the huge Pleistocene ground sloths, and the highly armored glyptodonts related to the armadillos and looking like great land tortoises (Fig. 134). Both of these stocks migrated into the southern United States and are found there in Pleistocene strata.

Euro-Asiatic connection with North America is indicated by the migration of American camels into China and India during the Pliocene.

At the same time the hollow- and twisted-horned antelopes came into America, along with the short-faced bears (arctotheres), now known fossil in Oregon, Mexico, and South America. The true bears arrived from Asia during the Pleistocene.

In Pliocene time the mammals attained their climax of development, and this continued into the Pleistocene. Here also was the time of their greatest wandering, since the proboscideans, horses, and camels were world-wide in their distribution. Then came the Ice Age and the ascendency of man, and one after another the magnificent mammals vanished. To get a picture of this climacteric late Pliocene mammal assemblage we must go to the tablelands of Africa, but here too it is doomed soon to disappear through the advent of the white man.

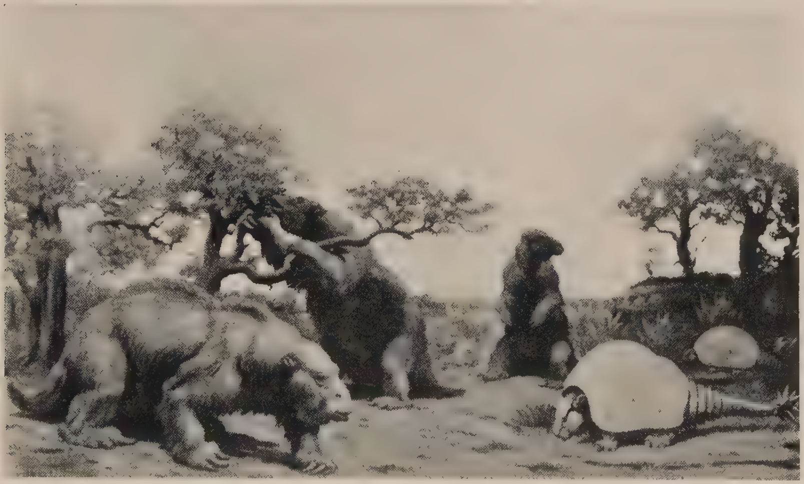


FIG. 134. — Two of the strange animals in the South American Pleistocene, the great ground sloth (*Megatherium*), and the giant glyptodont (*Dœdicurus*) with a length of over 10 feet. Painted by Charles R. Knight for the Field Museum of Natural History, Chicago.

We will next take up the evolution of a few striking stocks of Cenozoic mammals.

THE GIANT-BEASTS OR TITANOTHERES

Near the close of early Eocene time and shortly after the first appearance of the horses, there migrated into ancient Wyoming another stock of modernized mammals, represented by an odd-toed hoofed animal known as *Eotitanops*, smaller than a sheep and in appearance suggestive of a tapir (Fig. 135). This family, the titanotheres, beginning thus in small and as yet far from " giant " beasts, evolved into many new

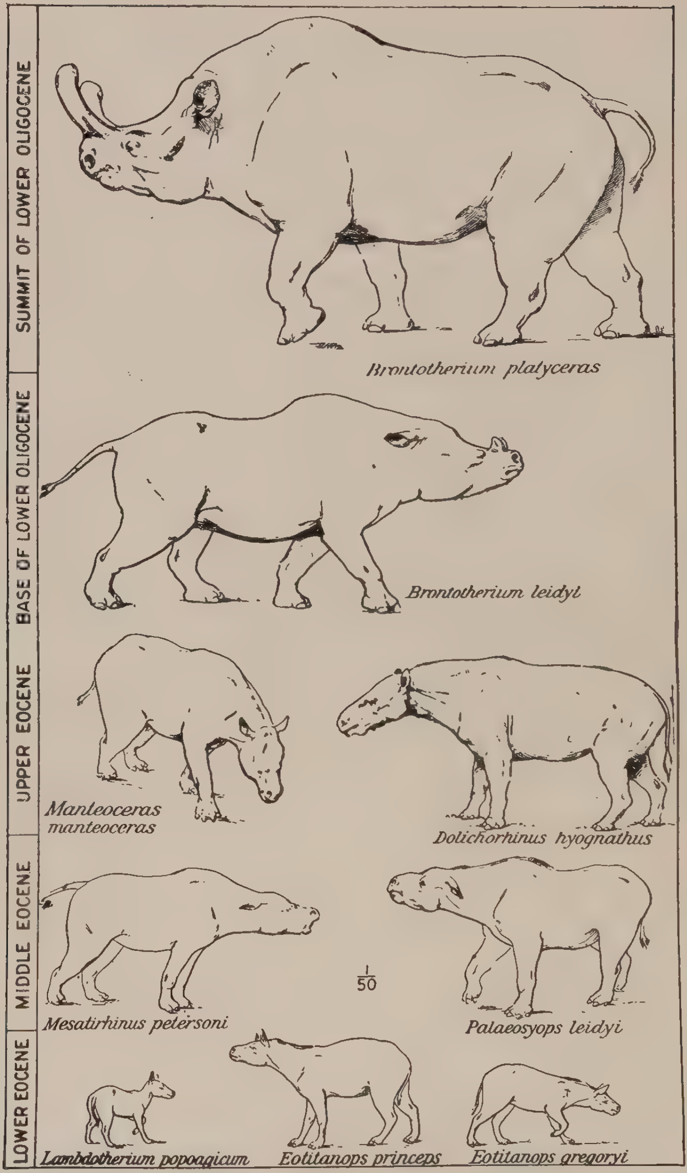


FIG. 135. — Restorations of nine species of titanotheres, living from the Eocene to the lower Oligocene. Note the progressive increase in size, and the change in the shape of the skull. About $\frac{1}{50}$ natural size. From Osborn.

and larger forms, and had as its final descendant a creature as large as an elephant, indeed, the largest mammal of its time (Fig. 135). Along with later migrants of other closely related stocks, these animals are found as fossils through 5000 feet of terrestrial strata laid down in something like 10 million years, but they died out rather quickly, geologically speaking, in early Oligocene time. During this interval the stock evolved into 12 subfamilies and 24 genera, with upward of 90 American species. Next to the horses, the even more highly differentiated titanotheres are the best known of fossil mammals, thanks largely to Osborn's two-volume monograph of 1929.

The titanotheres were a peculiarly American family, differentiating here far more than in Euro-Asia; they are, however, abundantly known in Mongolia (13 species), and sparingly in eastern Europe. According to Osborn, they died out in America apparently because the climate changed their home from a warm but not tropical, humid, forested, intermontane one to drier, more open and grassy plains country, and their browsing teeth failed to meet this change by evolving into the type necessary for grazing — an adaptation that was successfully made by the horses. In Mongolia the titanotheres lived on a while longer, but were exterminated there in the Oligocene because of the same environmental causes.

Brontotherium, the climax of titanothere evolution, was one of the most imposing products of mammalian history (see Fig. 135). In general, the titanotheres were heavy in body, with columnar legs and short feet, the latter supported on thick pads as in elephants. In all of them the front feet had four toes and the hind three, and in the older and smaller forms the toes and hoofs were more prominent. It is in the skull, however, that one sees the greatest amount of specialization, the teeth and feet being conservative. In the older forms, it was small, long and narrow, and devoid of knobs, but in the late Eocene the animals were larger and had small knobs over the eyes that with time steadily enlarged and shifted forward, until in the early Oligocene these bony " horns " had attained great size and were situated on the nose.

The " horns " were not like those of cattle, covered with a horny sheath, but were bony protuberances of the frontal part of the skull and in all probability were covered with a tough skin; they are believed to have evolved along with the fighting habits of these animals and the general increase in size and body. In all of the titanotheres the brain was comparatively small, but grew larger with time as is the rule in most mammals throughout the Cenozoic.

The Horses

In demonstrating the truth of evolution, the horses, above all organisms, are the best illustration of the working out of this doctrine — the "show animals" of evolution. Their history is coextensive with Cenozoic time, that is, runs through something like 60 million years, showing at once how slowly evolution works as a rule; and nowhere is this history so complete as in the Cenozoic formations of the United States.

The horse is the most useful and beautiful of man's domesticated animals, and has been one of the greatest factors in his civilization. In the early history of man, the horse served him as food, and later it became his chief means of travel and his beast of burden in agriculture and warfare. The horse is also among the most perfect and swiftest of organic running machines, as man loves to demonstrate in the race horse. In intercontinental migrations, and in adaptations to varied environments — from torrid to arctic climes — horses have had but two equals — elephants and man.

The horse family (Equidæ, from *Equus caballus*, the domestic horse) includes the living horses, zebras, and asses, and at least ten genera known only as fossils. The living forms so familiar to us are characterized by very long and slender feet, each composed of but a single functional toe, the third digit. The hoof is the equivalent of the nail or claw of the third finger or toe in other animals; horses, therefore, walk upon the very tip of the third finger nail. As the third toe in each limb supports the entire horse, it is necessarily much larger than in animals in which the weight is distributed among several digits. There is, however, on each side of the functional digit, *i.e.*, the "cannon-bone," a slender element known as the "splint bone." These are the vestiges of the second and fourth toes of the original five in the ancestors of horses (Fig. 136).

The teeth of horses are as peculiar to them as are their one-toed feet. The molars are long, square prisms which grow up from the gums as fast as they wear off on the crowns. The grinding surface exhibits a peculiar and complicated pattern of edges of hard enamel, between which are softer spaces composed of dentine and of a material called cement.

It is in these two characteristic features — feet and teeth — that the course of horse evolution displays itself most plainly, the number of toes being reduced from five to one, and the teeth altering from the short-crowned, cement-less browsing type to the long-crowned, cement-covered ones needed for grazing. Along with these features came a

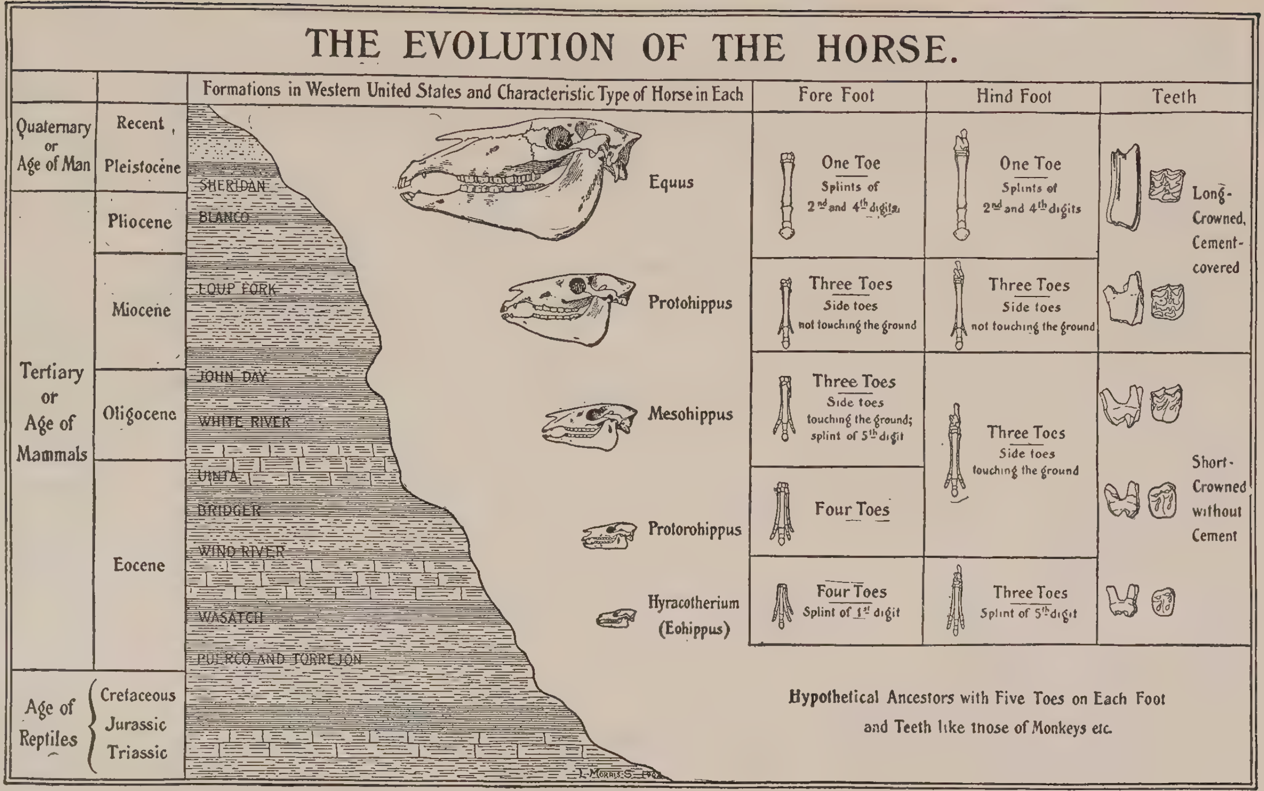

THE EVOLUTION OF THE HORSE.
Formations in Western United States and Characteristic Type of Horse in Each
Fore Foot
Hind Foot
Teeth
Quaternary or Age of Man
Recent
Pleistocene
Tertiary or Age of Mammals
Pliocene
Miocene
Oligocene
Eocene
Age of Reptiles
Cretaceous
Jurassic
Triassic
SHERIDAN
BLANCO
LOUP FORK
JOHN DAY
WHITE RIVER
UINTA
BRIDGER
WIND RIVER
WASATCH
PUERCO AND TORREJON
Equus
Protohippus
Mesohippus
Protorohippus
Hyracotherium (Eohippus)
One Toe
Splints of 2nd and 4th digits
Three Toes
Side toes not touching the ground
Three Toes
Side toes touching the ground; splint of 5th digit
Four Toes
Four Toes
Splint of 1st digit
One Toe
Splints of 2nd and 4th digits
Three Toes
Side toes not touching the ground
Three Toes
Side toes touching the ground
Three Toes
Splint of 5th digit
Long-Crowned, Cement-covered
Short-Crowned without Cement
Hypothetical Ancestors with Five Toes on Each Foot and Teeth like those of Monkeys etc.
L. Morris S. 1902

Fig. 136. — Diagram showing the evolution of the horse. After Osborn.

progressive increase in size, a lengthening of the lower jaws to accommodate the longer teeth, an elongation of the lower limbs, and a compensatory lengthening of the neck to enable the animal to graze.

The horse family has been traced back almost to the beginning of the Cenozoic without a single important break. Where their ancestors originated is not known, but it is believed that horses, rhinoceroses, and tapirs will some day be traced back step by step to a generalized common ancestor, probably with five toes. At any rate, the horses appear almost simultaneously in America and Europe in the early Eocene, the first representative being *Eohippus* (Fig. 132), the "dawn horse," no larger than a small dog, with four toes and the rudiment of a fifth (splint bone) in front, and three toes with two tiny splints behind. By the middle Eocene the evolutionary tendencies were under way, *Orohippus*, the size of a sheep, showing a slight reduction in the side toes, to be followed by a little more marked shrinkage in *Epihippus* of the late Eocene. In Oligocene time, *Mesohippus* (Fig. 136) and its contemporaries had three toes on all their feet, and a heightened tooth crown. *Parahippus* and *Merychippus* of the Miocene, in some species reaching the size of a donkey, displayed side toes that no longer touched the ground but hung useless at either side of the cannon-bone; in other words, these horses were beginning to walk entirely on the middle toe. *Merychippus*, moreover, had milk teeth that were short-crowned, with little or no cement, and permanent teeth with greater length of crown and quite heavily cemented, thus marking the transition from browsing to grazing type.

The Pliocene saw many new genera of horses; in nearly all, the side toes were practically gone, and the splint bones shortened. Among them, in the late Pliocene, side by side with the last three-toed horse, was the first member of the one-toed living genus *Equus* (Fig. 136). In the early Pleistocene this genus expanded into at least ten species, some of them larger than the modern horse, and spread all over North America, the best known form being Scott's horse (*Equus scotti*) from the Staked Plains of Texas. The genus is also found in South America and in Europe and Africa. Some of these equids continued to live on into the middle Pleistocene, but none are known in the later part of the epoch, and all horses had died out completely in North America before the advent of the red man. Our present wild horses are feral, that is, of domesticated ancestry, descending from the horses brought by the Spaniards; while the horses of Asia, Africa, and Europe are descendants of early Miocene horses that migrated from North America to Siberia by way of Alaska.

Interpreting the evolution of the horses in terms of the changing environment which lay back of it, the Eocene world in which *Eohippus* found itself had a cool climate, but this ameliorated as the period wore on, until conditions had become warm and moist enough to induce extensive forests, at least in the areas of the western Cordillera. Hence the early horses were forest-dwellers, browsing on an abundance of food from tree to bush. Over the Great Plains, however, was already setting in the aridity that was to become marked in the Miocene and to continue there to the present day. As this aridity increased, due to the elevation of the region, and brought with it decided cooling of the temperature, the forest areas shrank and the horses were driven out on to the open grassy plains. Here also was abundant food, but of a harsher nature that wore down the short-crowned teeth and necessitated the development of longer crowns and harder cement. Here, too, were enemies, and no shelter. Water was scarce and waterholes far apart. The race was indeed to the swift! The call for greater speed brought the horses literally " up on their toes," with the greater part of the weight coming on the middle digit. " To step off one toe, instead of stepping off several toes or the flat of the foot," says Matthew, who has studied more bones of fossil horses than all other workers together, " gives a sharp quick impulse forward. The little horses had to make it snappy if they were going to outrun and get away from their enemies." With this foot change came the gradual loss, through disuse, of the additional toes, and the elongation of the lower limb. With the greater necessity for using their wits in the struggle for existence came also progressive enlargement of the brain, especially the middle lobe where memory of place is located, until the living horse has a brain of very high grade, and its docility and ability to learn are notable. On the other hand, from its inherited psychology, dating back to the time when an impulse toward flight was of the greatest possible aid in survival, comes its tendency to leave suddenly any place where there is something it does not comprehend or fears.

It must not be inferred, from the above brief summary, that the evolution of the horse group was as simple and straightforward as might appear therefrom. There were, on the contrary, other genera of fossil horses besides those mentioned, and among these were conservatives as well as progressives. What has been done in the summary, for purposes of illustration, is to take those genera only that show most markedly the general line of evolutionary advance. In reality, evolution goes on, not always by progressions, but also by seeming digressions and even by retrogressions, but in the stocks that attain success the net result is an advance to higher physical organization and mental power.

The Elephants

Among the mammals of the Cenozoic, there was no group more spectacular in its evolution and distribution than the bulky trunk-bearing elephant stock, and among present-day land animals they still lead in size, strangeness of form, and bulk of brain (Fig. 137). Of living elephants there are, however, but two kinds, the larger, big-eared ones of Africa, some of which attain a weight of about 7 tons and a height of 12 feet at the shoulders, and the somewhat less heavy and smaller-eared type found in India and central Asia.

Elephant-like mammals are technically known as Proboscidea, the proboscis being the trunk which is their most characteristic feature. This is in reality the greatly elongated nose, nostrils, and upper lip, forming a very flexible and powerful muscular adjunct to the head, and serving many purposes but used chiefly in gathering food and water and conveying them to the mouth far above the ground.

The head of elephants is not only large, but is peculiar also in its great height as compared to its width; in other words, it is bulldog-like. The height of the skull is an adaptation to give greater muscular area, and, therefore, stronger leverage for the neck muscles which support the head and trunk. The upper part of the skull is, however, decidedly cellular. The greater transfiguration of the proboscideans took place in the head and in the trunk (see Fig. 137), beginning in long-headed forms with very short trunks and progressing steadily into the present high type of skull with long trunk.

Another striking feature of the proboscideans is their great tusks. These are in reality a pair of enlarged incisors, which grow continuously at the base and are pushed out; they wear to a blunt point but grow longer as the animal ages, reaching a length of 8 feet in the Indian species and 10 or 11 feet in the African. The female has smaller tusks or none at all. The cheek or grinding teeth, instead of being all in use at once, come into use successively, breaking through the jaw one after another and being gradually pushed upward and forward by the pressure of the tooth behind.

The earliest known proboscidean-like animals are found in the late Eocene and Oligocene of Egypt (*Mœritherium*, Fig. 137). The more primitive forms are thought to have been stream and lake dwellers, that is, amphibious in habit, and not until the group took to the forests and grassy plains did their distribution become so general. The main evolution centered in Asia, whence successive waves of migration spread in all directions. From Asia the deployment was both to the west into Great Britain, and possibly even to North America by way of an early

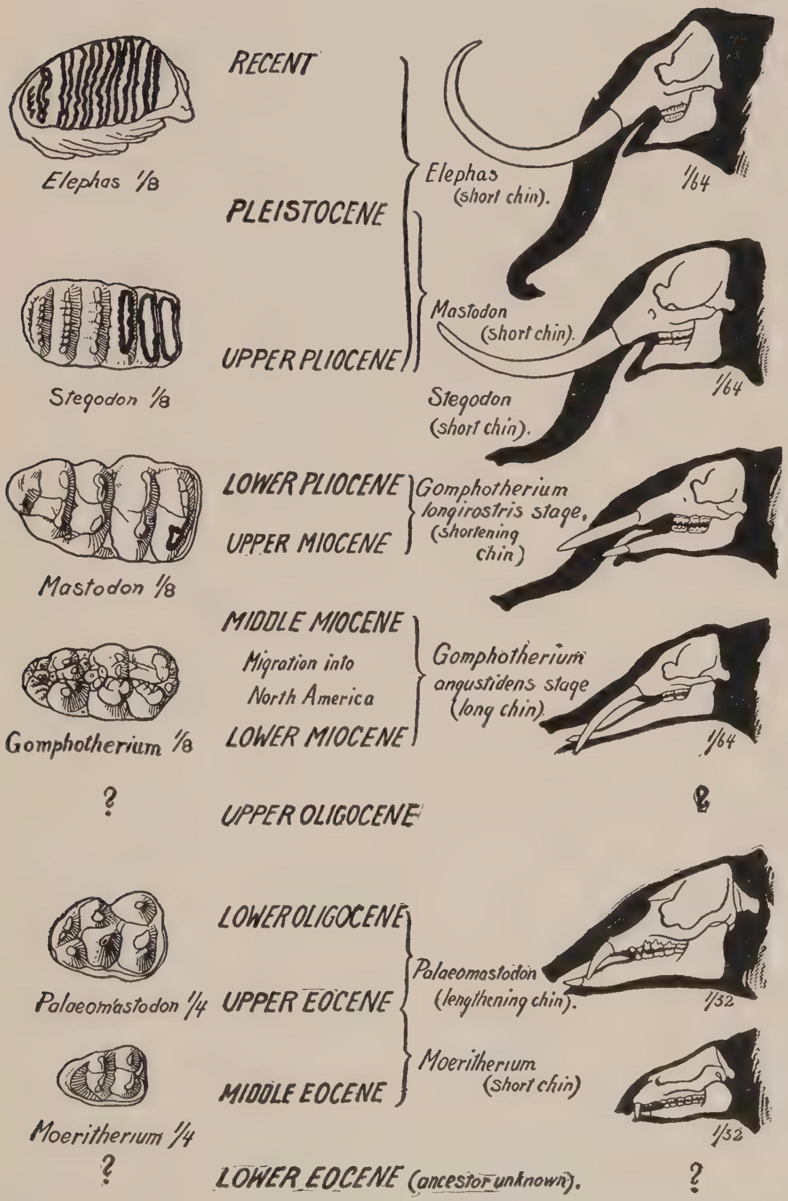


FIG. 137. — Evolution of the Proboscidea. On the right, a series of skulls with the flesh restored in silhouette. On the left, last lower molar. After Lull, from Scott's *History of Land Mammals.*

Miocene land-bridge connecting America and Europe across the Shetland Islands, Iceland, and Greenland; and eastward by way of Siberia to Alaska and the United States. Finally in the late Pliocene the elephants spread from North into South America. Hence the proboscideans have been world-wide travellers, equalled only by the horses and exceeded only by man.

Early in their history, the Proboscidea differentiated into two groups, mastodons and elephants, similar in appearance but with very different teeth. Of the former group, ten races have been recognized, and of the latter, six; only six of the sixteen failed to reach North America (Osborn).

The *mastodons* again divide into short-jawed and long-jawed types. The former derive from *Palæomastodon* (Fig. 137) of the early Oligocene of Egypt, the long-jawed ones from *Phiomia* of the same place and time. *Palæomastodon* was about the size of a tapir, with a narrow face and a well developed, flexible snout rather than a trunk. The tusks of the skull were short, compressed, and outwardly directed; those of the jaws, while larger, pointed straight forward. These tusks originated in the second incisors, the other front teeth remaining small. All of the grinding teeth were in place and functioned at the same time, which is not true of the later proboscideans. The limbs were like those of elephants.

From the short-jawed group, in which the trunk hangs free, came the well known American mastodon (*Mammut americanum*, Fig. 147, A), standing some 9 feet high at the shoulder, but shorter of limb than the true elephants. Skeletons of this mastodon are found from Florida to Alaska, from Connecticut to California, and from central Russia eastward throughout Siberia. The animal appears to have come from Asia and to have lived in the swampy regions in front of the last continental ice-sheet. It was known to the Indians and its bones are found at times associated with human artifacts (arrowheads, etc.).

The long-jawed mastodons, springing from *Phiomia*, had an extremely long and slender lower jaw, far exceeding in length those of any land mammal yet discovered. This lower jaw was armed with a pair of shovel-shaped tusks, used doubtless to dig out and uproot plants, a method of food-getting that was evidently advantageous, for the group spread rapidly and increased in size until *Trilophodon* (also called *Gomphotherium*) of the South Dakota Pliocene was almost as large as the American mastodon. In one of these American long-jawed forms, *T. lulli*, the lower jaw and tusks reached the enormous length of 6 feet 7 inches. (See Fig. 137.)

The two mastodon stocks crossed from Africa by way of a land-bridge through the Mediterranean from Tunis, Sicily, and Italy to Eurasia. This bridge was in existence in late Oligocene time.

The *elephants*, as distinguished from the mastodons, include, besides the living Indian and African types, three fossil races. The first of these were the very primitive stegodonts which lived in the tropical forests of India, the East Indies, and China from Miocene to Pleistocene time. *Stegodon*, of the late Pliocene, was quite elephant-like, with short, high skull; large, somewhat upcurved tusks; and free-swinging trunk. It survived into latest Pleistocene time and left its bones in the same beds with the earliest of the mammoths. The stegodonts are not, however, thought to be directly ancestral to the living elephants, which seem to appear suddenly in the Age of Man.

The other members of the elephant group all reached America. These were the mammoths, to be described in the next chapter.

The Rhinoceroses

The rhinoceroses are generally three-toed, and typically thick-skinned; as a rule, they have but little hair. They are browsers and grazers and live in forests, steppes, and marshes. The living forms stand from 4 feet to 6½ feet tall at the shoulders. The horns of rhinoceroses are peculiar in that they are neither hollow as in cattle, nor of bone, but are solid dermal growths made up of agglutinated hairs, and for this reason are never found fossil.

Since middle Pliocene time there have been no rhinoceroses in North America, but they once ranged over the continent from Alaska to Florida. In the early Eocene fauna of Wyoming, along with *Eohippus* and *Eotitanops*, appears a small generalized mammal called *Hyrachyus*, which may represent the ancestral stage of the rhinoceroses, though whether their evolutionary center was North America or Asia or elsewhere is a question. *Hyrachyus*, at any rate, was an active animal, ranging from the size of a tapir down to that of a fox, hornless, with four toes in front and three behind. The first true rhinoceroses, appearing in the Oligocene, were already differentiated into two marked groups. The hornless aceratheres (Gk. *a*, without + *ceras*, horn) (Fig. 139), which in early Oligocene times ranged widely over the whole northern hemisphere, evolved in the Miocene and Pliocene into forms as large as the living Indian rhino, with very powerful lower incisor tusks and long, swift-running limbs; less successful, apparently, were their pair-horned relatives, the diceratheres (Gk. *di* –, two), which had the horns side by side instead of one in front of the other as in all the other groups, and which ranged from Europe to the Rocky Mountains but did not live beyond the early Miocene. In size, the diceratheres were comparable to the tapir, and, like the aceratheres, they were long-limbed and slender-bodied, with fighting incisors (Fig. 138).

Extremely unlike the swift aceratheres and diceratheres was a third race of rhinoceroses, first seen in the early Miocene of France and later covering the whole northern hemisphere; these were the short-legged types represented in abundance in the Kansas and Nebraska Pliocene by the genus *Teleoceras* (Fig. 139), with heavy barrel-like body low-slung on very short legs, and with a tall thin wedge-shaped horn on the end of the nose in the males. These lumbering creatures were partly aquatic in habit, like the living hippopotamuses, which they resemble somewhat in body proportions, reaching a length of 10 feet, a height at the withers of about 4 feet, and a girth of 9 feet. That animals of this sort could have been world-wide travellers is one of the curiosities of paleontologic history.

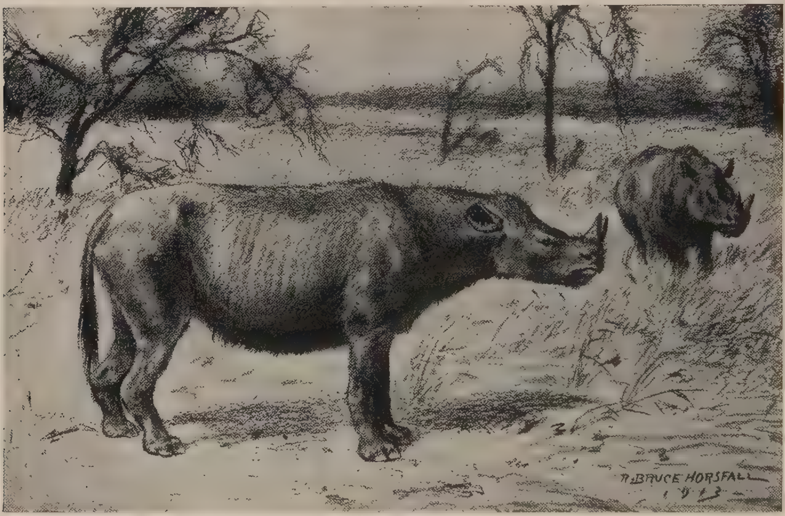


Fig. 138. — *Diceratherium cooki*, the small pair-horned rhinoceros of the lower Miocene of Nebraska. From Scott's *History of Land Mammals* (Macmillan).

The tandem-horned rhinoceros of present India (Fig. 139) belongs to a race that dates back to the Miocene, and in the late Pliocene ranged thence to England. The history of the single-horned Indian rhinoceros is less well known. The African form (Fig. 139), well protected by two large horns, the foremost of which is the strongest weapon of the kind owned by any quadruped, gave up the upper and lower cutting teeth and developed in their place thick lips of the grazing (white rhino)

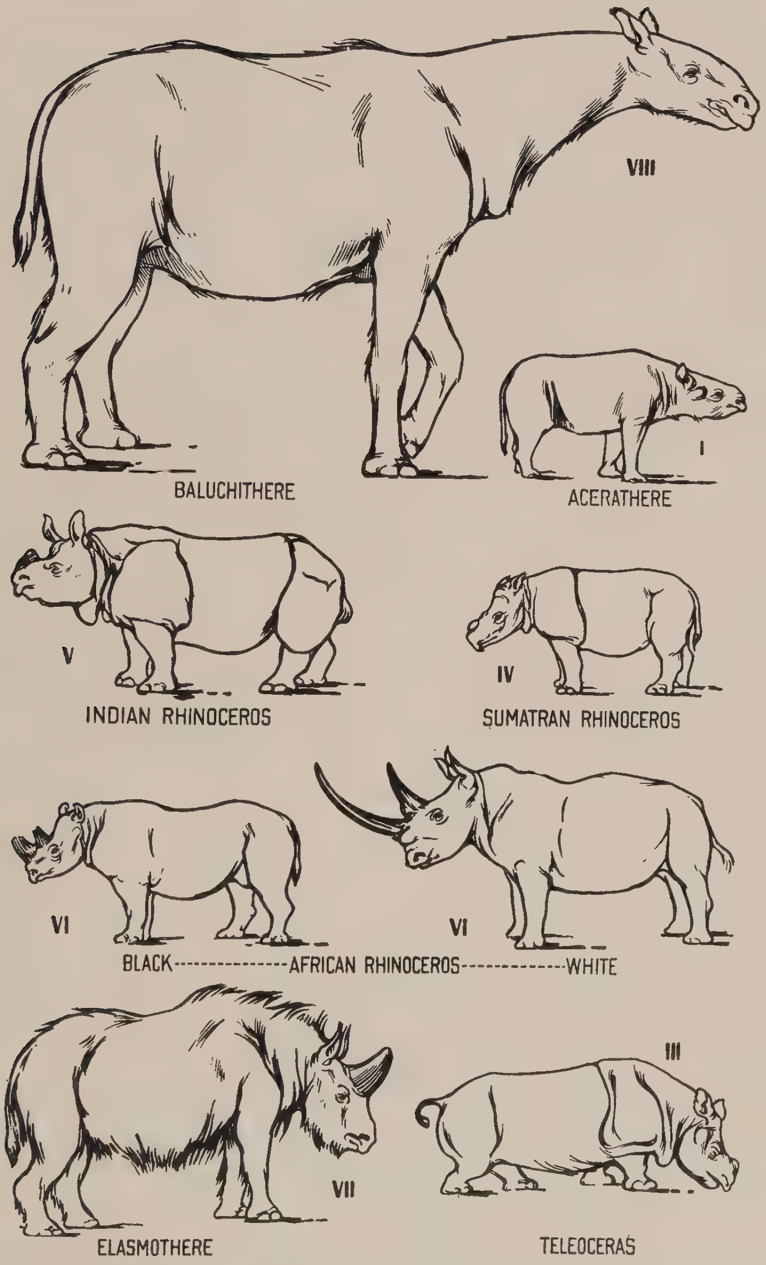


FIG. 139. — Rhinoceroses, living (facing left) and extinct, drawn to scale to show the great size of *Baluchitherium*. From Osborn.

or browsing (black rhino) type. To this race also belongs the woolly rhinoceros of the tundras of the Ice Age, contemporary of the woolly mammoth.

Latest of the rhinoceroses to become well known, and most striking of them all, is the giant *Baluchitherium* (Fig. 139) of the Asiatic Oligocene and Miocene, the largest mammal so far discovered. This strange beast was rather horselike in proportions, with long stilted limbs and a very long neck. The great head, 5 feet long and relatively narrow, was carried 14 to 16 feet above the ground, and was armed with terrible upper incisor tusks.

The Carnivora

The so-called " balance of life " in any fauna is maintained by two elements, the herbivores, or plant-eaters, and the carnivores, or flesh-eaters. Both are, of course, in the last analysis, dependent on the plants. The herbivores, in general, are the more numerous, the carnivores the more intelligent. In fact, among the latter the increase in brain, especially of the cerebrum or upper lobes, is a marked feature in their evolution.

This carnivorous element may be traced in the faunas ever since the Cambrian, from the trilobites to the cephalopods to the armored Devonian fishes; through the predatory reptiles of the Permian to the great *Tyrannosaurus* among the dinosaurs; thence through the flesh-eating archaic creodonts to the wide array of carnivorous mammals living to-day.

The one feature common to all modern carnivores is the specialization of one pair of the teeth for the cutting or crushing of flesh or bone. These so-called carnassial teeth are the fourth premolar of the upper jaw and the first true molar of the lower, the teeth behind being smaller, and variable in number in the different families. The early carnivores, however, had no specialized carnassials, and used instead any one of the three pairs of back teeth for flesh-cutting or crushing. From this generalized type developed five distinct groups, each using a different combination of upper and lower molars to form the cutting or crushing pair. Four of these groups died out with the rest of the archaic mammals, but from one of them, the Miacidæ, branched out in turn the seven families of modern flesh-eaters: dogs, bears, raccoons, weasels, civets, cats, and hyenas.

The evolution of the *dogs* is as yet not well known. By the late Eocene, very small canids, more like weasels and civets than dogs, and not yet swift of foot, were present, and may have given rise to the foxes. *Daphœnus*, of the Oligocene, was about the size of a coyote, probably a great jumper, with a heavy leopard-like tail; it had many cat-like features. Among the Miocene dogs was the huge *Dinocyon* (" terrible dog "), as large as the Kadiak bear and bear-like in appearance, though probably having a long and heavy tail; and continuing the reputation of the race in the Pleistocene was the huge *Canis dirus*, the " grim wolf of the tar pits," found in the famous asphalt death-trap of the Rancho La Brea, California (see Fig. 148).

The true *bears*, which are omnivorous rather than strictly carnivorous, are recorded first in the Miocene of the Old World. They are known with surety only in the Pleistocene in North America, and their origin and history are uncertain. *Ursus spelæus*, the Pleistocene cave-bear, equalling the largest of the Recent bears in size, was well known to prehistoric man, and figures frequently in his art.

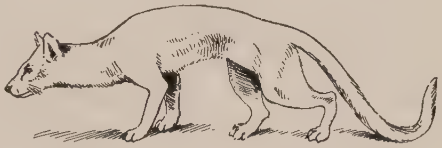


FIG. 140. — *Cynodictis*, a small foxlike dog of the Oligocene. After Horsfall, and Scott.

Phlaocyon, the oldest known member of the *raccoon* tribe, lived in the early Miocene, and links with the Oligocene dog *Cynodictis* (Fig. 140). The rare fossil remains indicate animals of small to moderate size, largely arboreal, and again not entirely carnivorous. They are now entirely American with one Asiatic exception. The *weasels*, polecats, badgers, and the like, forming the family Mustelidæ, are known from the late Eocene in Europe and the Oligocene of North America, though their skeletons are in the main too small and fragile to be preserved. One of them, however, *Megalictis* (" great weasel ") of the Miocene, was much larger than any known member of the present family, with skull nearly equal to that of a black bear. The mustelids are as a rule fiercely, and often wantonly, carnivorous.

Of the three remaining carnivore families, the civets, genets, and mongooses, the hyenas, and the cats, the last is by far the best known and the most interesting. In their dentition the *cats* are the most highly specialized of all the flesh-eaters, and to aid in making their kill they have wicked retractile claws. They diverged early into two types, the biting cats, which include the present felines, and the stabbing cats, which are all extinct (Fig. 142). Each type was an adaptation to a certain kind of prey, the biters living along with the thin-skinned cursorial hoofed animals such as the deer, and the stabbers pursuing the slow-moving, thick-skinned elephants, sloths, and the like. Each division had its representatives from the early Oligocene on, the two showing a parallel evolution after they came out of some unknown miacid of the Eocene. Most primitive of the cats was *Dinictis*, considered to be almost at the parting of the ways between the two types. It was a markedly cursorial form, as its restoration shows (Fig. 141; also Fig. 142, A). Thence the biting line runs through *Nimravus* ("ancestral hunter," Fig. 142, C) of the Oligocene and Miocene (and possibly *Pseudœlurus* of the Miocene) to the genus *Felis* (Fig. 142, E), which is present as far back as the Pliocene and includes the modern lions, tigers, leopards, and their kin.

The stabbing cats begin with *Hoplophoneus*, the "armed slayer" of the Oligocene (Fig. 142, B), with a body and tail similar in proportions to those of the modern leopard, but with more powerful limbs, and with the upper canine already long, thin, curved, and finely serrate. Following this form the line is carried on by *Machœrodus* ("dagger tooth," Fig. 142, D) of the Miocene to Pleistocene, known from the skull only, and with the stabbing tooth well developed. The terminal member of the line is *Smilodon*, the great sabre-tooth tiger of the American Pleistocene (Figs. 148 and 142, F), a fearsome beast in which the scimitar-like stabbing upper canine reached a length of 8 inches or more. To furnish leverage for the use of this deadly weapon, the neck had thickened, and the back and loins were stouter than those of modern cats. The extremely powerful limbs were relatively short, as was the tail. *Smilodon*, poised for a rush at one of the huge contemporary ground-sloths, may well stand as an epitome of mammalian cruelty.

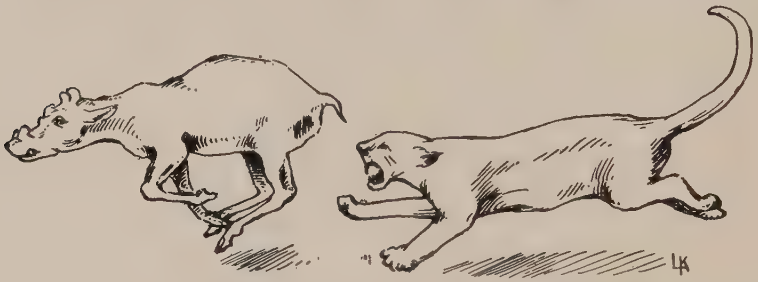


FIG. 141. — *Dinictis*, most primitive of the cats, shown chasing the early ruminant *Protoceras*. Oligocene. After Knight, and Osborn.

For the wonderful history of the American Cenozoic mammals we are indebted, first, to the great trio of American vertebrate paleontologists of the last century: Joseph Leidy and Edward Drinker Cope of Philadelphia, and Othniel Charles Marsh of Yale; and in the second place, to another trio who have carried forward this work in more recent years:

Henry Fairfield Osborn of the American Museum of Natural History, William Berryman Scott of Princeton University, and the late William Diller Matthew, formerly of the American Museum, more recently of the University of California. Any such summary of mammalian evolution as is given in the foregoing chapter must of necessity be based largely upon the work of these eminent paleontologists.

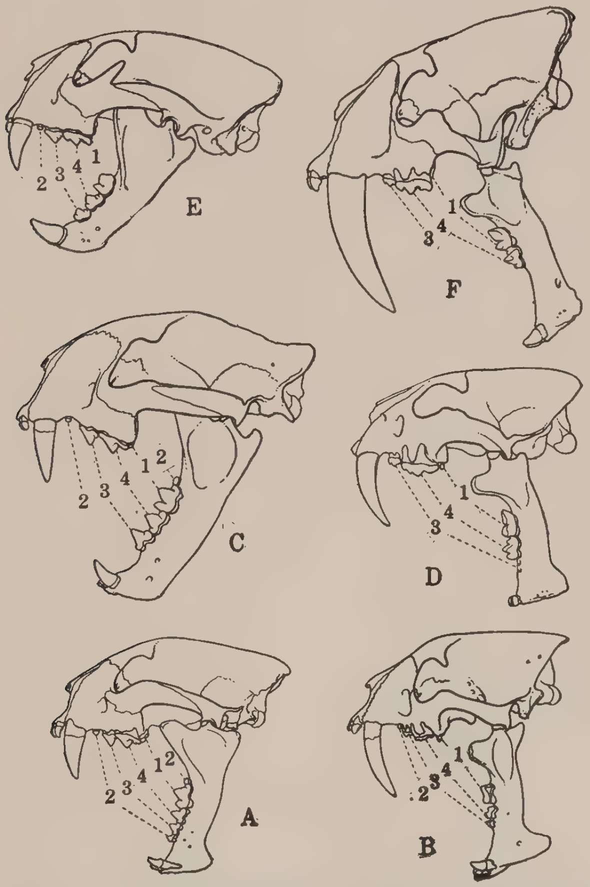


Fig. 142. — Skulls of biting (left) and stabbing cats. *A*, *Dinictis*, and *B*, *Hoplophoneus*, Oligocene. *C*, *Nimravus*, and *D*, *Machærodus*, Miocene; *E*, *Felis*, and *F*, *Smilodon*, Pleistocene. After Matthew.

CHAPTER XX

PLEISTOCENE TIME AND THE LAST GLACIAL CLIMATE

The Pleistocene, the final division of the Cenozoic era, and hence of geologic chronology, though brief as compared with the older divisions, was one of the critical times in the history of the Earth. At the beginning of this century about 400,000 years was assigned to the Pleistocene, but now its length is generally conceded to be a million years, and in California the physical evidence appears to call for about twice that duration.

The distinguishing feature of the Pleistocene was its very extensive glaciation; in fact, there appear to have been a series of glaciations, and ice-sheets covering about 12,000,000 square miles of the Earth's surface existed at one time or another during the epoch in the temperate and colder regions of the two hemispheres, 7,000,000 in the northern hemisphere, and 5,000,000 in the southern, most of which is in Antarctica (Fig. 143). This is all the more remarkable when we consider that the ice-sheets were mainly of the low lands, and that the climates for a very long time previous had been mild. All of the water of these ice-sheets had been taken from the oceans and precipitated as snow on the continents, the decreases of temperature being such that the snow line (see page 83 of Part I) was lowered about 4000 feet below its present limit, and the sea-level in the tropics lowered somewhere between 165 and 500 feet. When all the present ice-sheets are melted away, sea-level in the tropical regions will be raised from 50 to 140 feet.

The loading of the lands with so much ice caused the crust to subside in the areas of the ice-sheets, while the regions immediately outside of the latter were apparently somewhat upwarped. The surface of the glaciated lands, was, therefore, more or less unsteady, warping up and down some hundreds of feet in consonance with the changes going on in the ice-fields during Pleistocene time. In addition, broad crustal movements unrelated to the glaciation had been in progress during the Pliocene and continued at intervals in the Pleistocene. As a result of these combinations of several causes, the streams and shorelines of the glaciated areas generally show at the present time the marks of extreme youth. Sharp gorges, drowned channels, barrier beaches, and elevated strand lines indicate uplift, while drowned channels are produced by subsidence.

The development of such immense ice-fields upon the lands and the attendant reduction of temperature also meant the formation of vast areas on which no life or at least but little could exist. The Pleistocene was, therefore, a critical time in the history of the Earth, especially for the plant and animal life of the glaciated lands and the shallow-water life of the northern and southern oceans. The cold waters, pouring into the oceans, sank into the depths, and the conditions there also became critical for the sparse life. In the shallow waters of the warm parts of the ocean, however, there was almost no change in the environment, and consequently there is recorded here almost nothing more than the usual evolutional faunal alterations.

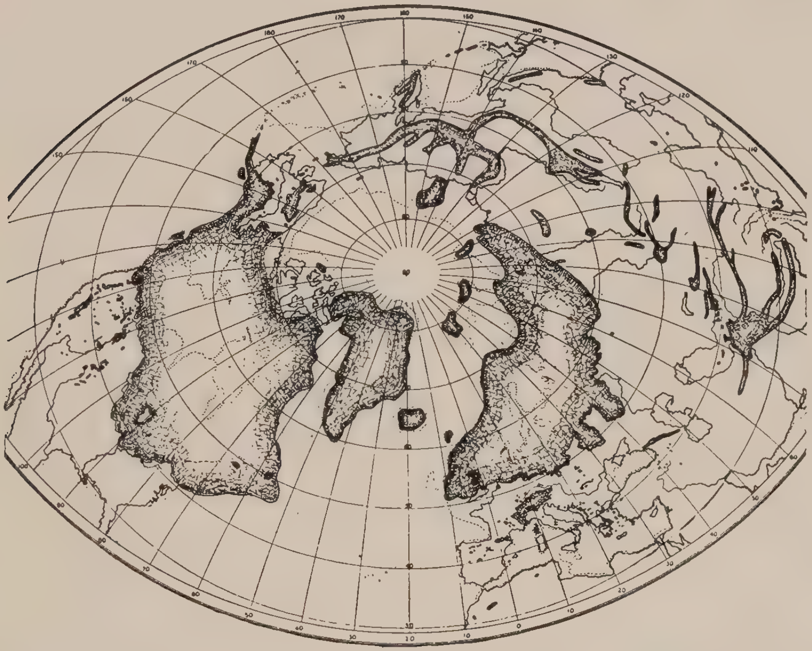


Fig. 143. — Maximum extent of areas glaciated in the northern hemisphere at one time or another during the Pleistocene. After Antevs.

The record of the areas where the ice-fields prevailed during this "Great Ice Age" consists in the main of a varied and most often a heterogeneous series of continental deposits, the Diluvium or Deluge material of the older philosophers, and the drift or tills of modern students of Earth science. Characteristic of this drift are the included erratics, the "boulder beds" known as till and consisting of unassorted rock débris, the banded or varved clays, and a striated or scoured rock floor. Soils are mostly yellowish and thin, or absent, and everywhere occur lakes of varying sizes occupying the ice-made basins.

Outside of the areas of glaciation the Pleistocene strata are in general like other continental formations laid down under moist and warmer climates, but the marine record is nearly everywhere very scanty.

There are wind deposits of sand and dust along the rivers and the shores of lakes, and in various arid areas occur accumulations of dust (loess); elsewhere there are sediments of rivers and lakes and the deposits made by springs, asphalt pools and fillings of caves and sink-holes often abounding in bones, peats and marls of marshes and ponds, lavas and ashes in the areas to the west of the Rocky Mountains, and finally the fresh-water, estuarine, and marine accumulations along the borders of the continent. All of these deposits are apt to be thin and localized.

The glacial clays in many places in northern North America and Europe are regularly laminated, and De Geer of Sweden has demonstrated that this banding was due to seasonal deposition. A darker and thinner (winter) and a lighter and thicker (summer) band are laid down each year, and each pair is called a varve. Counting these layers throughout Sweden on the basis of 1500 localities, De Geer has determined that the ice-sheet began to leave the southern end of that country 13,500 years ago, and northern Germany about 16,300 years ago (see page 113 of Part I). This chronologic method is known as the "Swedish time scale."

The Pleistocene was followed by the *Recent*, or present time, with a length, since the ice-sheets began to melt away, of something like 25,000 years. As man has dominated the organic world since the beginning of the Recent, this is also known as *Psychozoic time*, or the Age of Mind.

General Distribution of Glaciation. — In the discussion of Pleistocene glaciation it should be recognized that the ice has only partly withdrawn, Greenland and Antarctica being still mantled with continental ice-sheets. It is the excess of glaciation beyond the present areas that is to be considered in the discussion of the wide distribution of the ice-fields of the Pleistocene.

Over 4,000,000 square miles of North America and Greenland was ice-covered at one time or another during the Pleistocene epoch, and less than 3,000,000 square miles of Europe. The continental ice-sheets were, therefore, localized, though the effects of the glacial climate were world-wide. All of the northern portion of North America, Greenland, and Alaska were covered, but not the island archipelago west of Greenland.

There were three great *centers* of snow accumulation in North America, namely, in the lowlands of the district of Keewatin, in the highlands of eastern Labrador, and in the mountains of Cordillera (Fig. 144). It was from these centers of snow gathering that the ice-sheets spread radially by slow outward creeping. The *Keewatin ice-sheet* was the most extensive, covering the great medial flat area of the continent

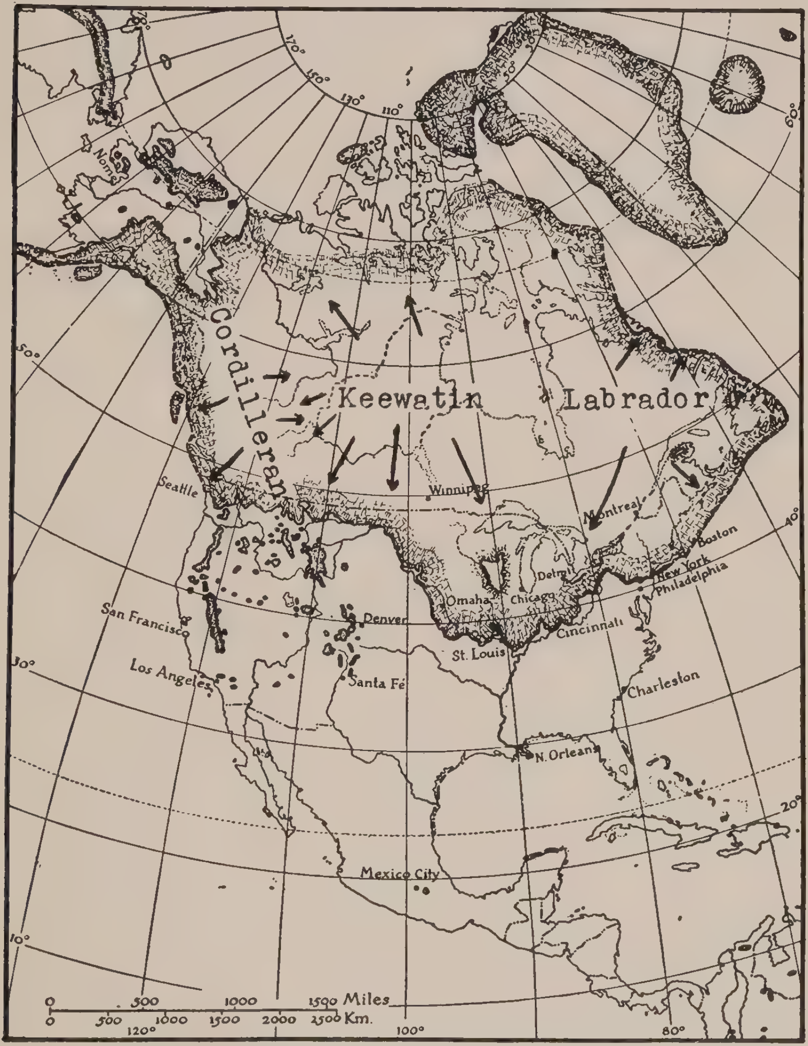


FIG. 144. — Pleistocene glaciation in North America, showing the three centers of ice accumulation. The entire mainland between the mouth of the Mackenzie River and Coronation Gulf, long. 114° W., was also glaciated. After Antevs, with lettering and arrows added.

southward into Missouri and westward into the high plains to within 800 to 1000 miles of the Rocky Mountains. The *Labradorean ice-sheet* was not much smaller, and extended from northeastern Labrador southwestward for 1600 miles to the Ohio River. The main flow of the ice was southward toward the region of melting, marked by greater warmth. *Newfoundland* and *Nova Scotia* appear to have had independent ice-sheets, while *Greenland* was glaciated more extensively than now but not completely across Davis Strait so as to connect with the Labradorean mass. The *Cordilleran ice-sheet* covered all of the Cordilleran area from Alaska southward into northern Oregon, Idaho, and Montana. Farther south there were local alpine glaciers in the Rocky Mountains, the Coast Ranges, and the Sierra Nevada of California.

How thick the Keewatin and Labradorean ice-sheets were is not known. It is widely held, however, that they must have been some thousands of feet in depth to have enabled them to flow southward with a descending grade across the higher irregularities. Geologists as a rule believe that the thickness at the centers of ice dispersion could not have been less than 4000 to 6000 feet, and that it may have exceeded this average depth (up to 10,000 feet).

Alternating Cold and Warm Stages. — In most of the glaciated regions there is evidence of more than one sheet of till. Several considerations indicate that such superposed glacial deposits are the results of distinct glacial stages separated by relatively long warmer intervals when the ice-caps had disappeared or at least had retreated considerably to the north (see chronologic table in the next chapter).

Evidence for this striking conclusion is to be seen in (1) remains of warm-climate animals found in interglacial deposits of stratified sands, of peat, or of old soils; (2) differences in the degree of leaching of younger and older tills; and (3) differences in the degree of surface erosion in the different sheets of till.

First, during the epochs of glaciation arctic animals migrated southward with the ice front, as shown by the fossil remains of the musk-ox and the woolly mammoth in Kentucky, Arkansas, and Utah, and of the reindeer, cave-bear, arctic fox, etc., in central Europe. At such times of course the warm temperate and subtropical animals and plants retreated still further south. However, certain of the interglacial deposits contain abundant remains of warm temperate creatures; for example, the hippopotamus and lion in England or the sabre-tooth tiger, peccaries, tapirs, camels, horses, and Columbian and imperial elephants in the southern United States. It is clear, then, that at this time the climate in the latitude of England and the southern United States was rather warmer than it is to-day, hence the ice-caps must have disappeared, or at least have retreated far to the north. That the retreat was general is indicated by deposits of peat and by old soil lying above the older till and beneath the younger.

With reference to degrees of leaching in tills of various ages, in newly formed till all the boulders are of fresh, unweathered rock and the paste is of fresh "rock flour." When exposed to weathering, the boulders in time crumble to pieces and the fine material is leached of its soluble carbonates. As a result of leaching and decay there is formed at the surface of old tills a sticky clay or gumbo which, because of its association, is known as *gumbotil*. The youngest known till (Wisconsin), which has been exposed for perhaps 25,000 years, shows little effects of weathering; its rock fragments are still as fresh as quarried stone and no gumbotil has formed upon it. In places the older tills below this are, on the contrary, deeply decayed and leached, and it is evident that they have been weathered for many times more than 25,000 years. The degree of weathering and the thickness of the residual gumbotil thus give evidence of the comparative ages of the superposed sheets of till. Hence it is clear that some of the interglacial epochs have been vastly longer than the time since the last glaciation, and we are faced with the possibility that the present is but an interglacial epoch.

The degree to which the irregular surface of the till has been eroded also varies with the time since it was left by the melting ice.

It may be a source of wonder that unconsolidated till, peat, and soil are not destroyed by a re-advance of the ice. They would be, of course, in the growing field of the ice-cap, but near the margins of the ice-field where the thickness is reduced and the glacier overladen with its own débris, the ice may override and not erode even soft material. It is clear, however, that if successive advances were increasingly extensive, each would largely or wholly destroy the record of the previous one, but if each were less extensive than the last, a marginal fringe of each would remain, and they would overlap.

It is not surprising, therefore, that the number of *known* glacial epochs differs in various regions. For example, in New England where the last ice-sheet pushed well out to sea, there is no record of any of the previous glaciations. The most complete record is that of the upper Mississippi Valley (especially Iowa) where five distinct glacial epochs are recorded.

One of the interesting by-products of the alternating Pleistocene climates was Lake Bonneville, once 20,000 square miles in extent and 1000 feet deep, of which Great Salt Lake, Utah, is the present remnant, now shrunken to one-tenth its former size and with a present average depth of 20 feet (see Part I, pages 142–143). Lake Bonneville had two high stands of water, and during the last one the lake drained out to the north. Great Salt Lake is estimated to contain 40,000,000 tons of common salt and 30,000,000 tons of sodium sulphate, testimony to the enormous amount of evaporation that went on during its shrinkage.

Effects of the Glaciation. — The geologic work done by glaciers in general is described in Chapter V of Part I. Erosion by the continental ice-sheets was unequal and the deposition of the drift materials was especially irregular in distribution. From this it follows that the drainage system of the land was deranged and considerably modified. River valleys were locally filled by the drift to depths ranging up to 400 feet, or partially covered over by the ice, forcing the drainage around its front. In fact, the drainage of the glaciated areas was in certain regions revolutionized. The Ohio and the Missouri — the master streams of the United States marginal to the glaciated area — were built up from previous systems, and a host of their tributaries within the glaciated area suffered marked changes.

All ice-sheets push out lobes along the preëxisting valleys, and those of the Great Ice Age were no exception to this rule. Accordingly, the Keewatin ice-sheet, when it finally melted and retreated across the area of the Great Lakes, had lobes that extended along the ancient valleys (see Fig. 75 of Part I), scouring them deeper, and leaving in front, as the ice receded, small lakes that grew to ever greater proportions. The first to appear were Lake Chicago, the beginning of Lake Michigan; Lake Saginaw, a part of the future Lake Huron; and Lake Whittlesey, which was of considerably larger extent than its descendant, Lake Erie. At this time, certain of the present small rivers were large, as the St. Croix, Wisconsin, Rock, and Illinois, draining the vast melting waters of the Keewatin ice-field into the Mississippi River. In central New York the " Finger Lakes " were considerably larger than they are now and their waters for a long time drained into the Susquehanna River, and later through the Mohawk and Hudson rivers. Finally, when the ice had retreated well into Canada, all the Great Lakes were connected far more widely than they are now and drained out eastward through the Ottawa and St. Lawrence valleys. It was this eastward drainage that originated Niagara Falls, which formerly began at Lewiston, New York. It is thought that the making of the gorge by the Niagara River from Lewiston to the present Falls has taken something like 10,000 years (see Part I, page 53).

When the ice-sheets had finally retreated into Canada and across the St. Lawrence Valley and Lake Ontario, the Atlantic Ocean found the once glaciated lands depressed, and the waters, increased in volume by the melting glaciers, entered the depression and filled it several hundred feet deeper than now. This was, therefore, a time of greater inland or epeiric seas than at present, and evidently it was at some time in the Pleistocene that Hudson Bay appeared, since in the western part of the bay, on the hillsides up to a height of 600 feet, occur marine strata of this epoch but no older ones. In other words, a great part of eastern North America sank under the enormous load of the ice-sheet, and when the latter vanished, the rising Atlantic flooded deeply Hudson Bay, the St. Lawrence and Ottawa valleys, all of Lake Ontario and Lake Champlain, and southward to the east of Lake George. Marine shells and the bones of whales and seals are found about Lake Champlain at elevations up to 440 feet above the present level of the water, at 520 feet near Montreal, and at 480 feet near Ottawa (see page 138 of Part I).

At no time in the Pleistocene earlier than the St. Lawrence marine invasion just described is the continent known to have been invaded by the oceans to any great extent. The marine strand line was not, however, a constant one during the Pleistocene, but oscillated up and down within some hundreds of feet, due to the subtraction of water as vapor from the oceans and the piling of it upon the continents in the solid form of snow and ice. Geologists have pointed out that when the great ice-sheet existed on the land, the oceanic level between 30° N. and 30° S. must have been lowered between 165 and 500 feet in the region of the equator, the amount of depression depending upon the mass of the continental ice-sheet. During the Pleistocene warm intervals, the ice of the lands was more or less completely melted away and the water returned to the oceans, thus raising the strand line. When the ice began to accumulate on the lands, the oceanic level was lowered and the continents enlarged. At these times of lowered strand lines the seas everywhere began to cut more or less wide shelves or sea terraces into the lands, and when the waters returned it was upon these flooded shelves and those of the oceanic islands that the warm-water reef-corals began their making of the thick coral-reef limestones.

Siberian Tundras. — Curiously, the low lands of Siberia had no continental glaciers during the Pleistocene (see Fig. 143), in spite of the frigid climate that country must have experienced. The lack of glaciation was undoubtedly due to insufficient snowfall. Even now the precipitation is slight and if the country were hot it would be almost a desert. The winters here were very cold, but with little snow, freezing the ground deeply and in the course of time piling up the ice with interbedded sheets of soil and erosion material. Arctic Siberia is therefore a vast plain called a *tundra*, which means frozen ground. Commonly it is frozen to depths of many tens of feet and even some hundreds of feet; one pit at Yakutsk goes through such ground for 380 feet. During the summer the ground thaws to depths of from 1 to 3 feet, and the tundras are converted into swamps with small lakes. The tundras may have had their origin at the beginning of Pleistocene time. Similar tundras are of wide extent in Alaska. The Siberian tundras are famous for their well preserved corpses of mammoths (see Chapter III), rhinoceroses, and other extinct mammals. Ivory, in fact, is very common and is much sought for on the New Siberian Islands and adjacent shores. The Alaskan tundras yield similar remains, though far more rarely (see Fig. 145).

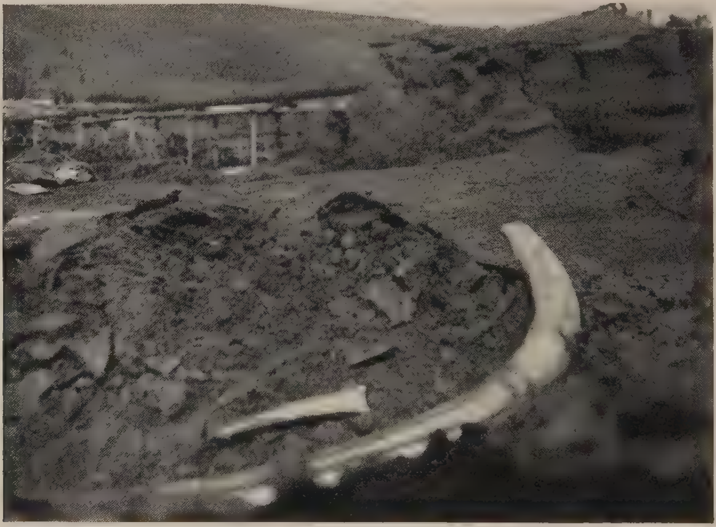


Fig. 145. — Mammoth tusk and horse limb bone, lying as they were uncovered by hydraulic stripping operations in a bank of frozen Alaska muck. Length of tusk, 11½ feet. American Museum of Natural History.

Causes of Glacial Climate

As yet there is no widely accepted explanation of why the Earth from time to time undergoes glacial climates, but it is becoming clearer that they are due rather to a combination of causes than to a single cause. Probably the greatest single factor is high altitude of the continents, since all of the best known and widespread glacial climates have occurred at or shortly after a climax of diastrophism, when the lands were highest and largest. In addition, at these diastrophic times the great chains of new mountains alter the general direction and constitution of the air currents that are prevalent when the lands are low. Furthermore, it must not be forgotten that when the lands are highly emergent, the formerly isolated lands are connected by land-bridges that more or less alter the oceanic circulation and therefore the local temperature.

It is impossible, however, to explain the repeated glacial and interglacial epochs of Pleistocene time on the grounds of diastrophism (" hypothesis of elevation ") alone, since we would be forced to the supposition that the continents were repeatedly elevated to great heights and depressed to low levels within relatively short geologic intervals. However, the interaction of other factors may at times have conspired with continental elevation to produce the climatic oscillations of the Pleistocene.

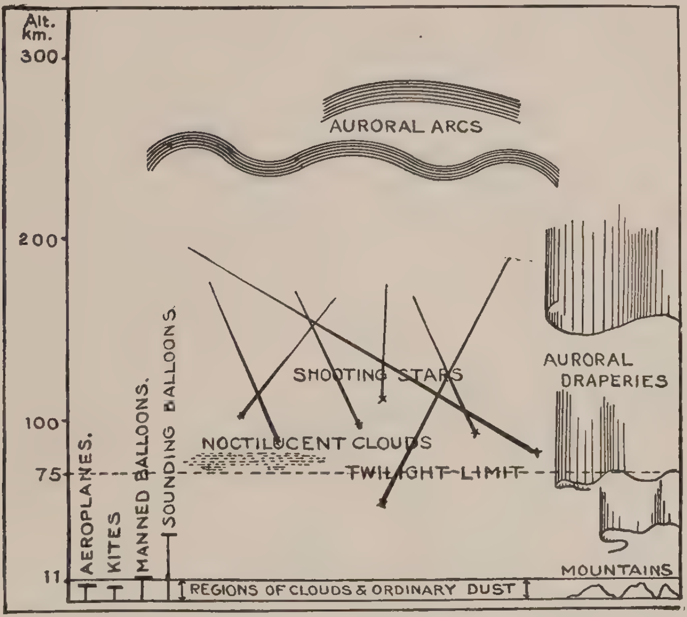


Fig. 146. — Sources of information concerning conditions in the air. From Humphreys' *Physics of the Air.* Reprinted by permission of McGraw-Hill Book Company.

Most promising of these postulated factors seems to be a change in the composition of the atmosphere, especially in its content of water vapor and of carbon dioxide (" atmospheric hypothesis "). It is the presence of these minor constituents in our atmosphere that furnishes most of its capacity to absorb and hold the warmth from the Sun. Their depletion would make of the atmosphere a thin and feeble " blanket " like that encountered at great altitudes.

At present only about 0.3 per cent of the atmosphere is carbon dioxide but there is approximately eighteen times as much of this gas in solution in the oceans as there is in the atmosphere. The solubility of CO_2 in sea water varies inversely as the temperature, and there is an easy interchange between the marine waters and the atmosphere. Now, if the temperature of the oceans be reduced, they tend to absorb more CO_2 and thus to rob the atmosphere. Hence when continental uplift reduces world temperatures there is depletion of the CO_2 from the atmosphere, leading in turn to still further reduction of temperature. At the same time also the rejuvenated erosion leads to rapid loss of CO_2 through the weathering of the expanded land areas. The cumulative result may thus lead to a glacial epoch.

After a time of glaciation, during which most of the CO_2 had been taken up by the oceans and an equilibrium established, any new factor that would temporarily raise the general temperature would upset the balance and reverse the process, for the warming of the ocean water would drive off more CO_2 into the atmosphere, thus increasing its heat-gathering capacity and inducing still further additions from the ocean water. The warmer air would also hold more moisture, increasing still further the warmth of the atmosphere. Thus a warm interglacial epoch might shortly follow an ice age.

The most probable irregular factor which might start such a reversal of the process seems to be actual variation in the heat radiated from the Sun. It is now well known that the Sun's heat as measured in instruments varies frequently from 3 to 5 per cent, and sometimes as much as 10 per cent. A solar change of 5 per cent continued for six months, it is thought, might well alter the mean temperature of the lands 3° to 6° F., which would make the difference between an unusually hot and an unusually cold season. Moreover, if the mean temperature of the Earth were to fall 9° to 11° F., and were to remain thus low for a sufficient length of time, meteorological conditions would be so altered that a large part of North America would be covered with ice down to about the fortieth degree of latitude, and Europe would suffer a corresponding glaciation.

When the lands are low and the seas widespread, slight changes of temperature are regulated and equalized by ocean currents and winds, and no marked results are felt. Great continental elevation reduces the temperature to a critical point, however, where minor changes may start a depletion of CO_2, which would become cumulative until a glacial climate would be brought on, or may break the equilibrium and reverse the process.

Another factor of the "atmospheric hypothesis" is dust in the air. A single explosive volcanic eruption can throw into the upper atmosphere so much dust that it will take from one to three years to settle down upon the Earth's surface. Dust in the air decreases the temperature of the Earth, and volcanoes were very active in Pleistocene time. Accordingly the amount of dust in the atmosphere may be the deciding factor when combined with highlands, enlarged continents, changed atmospheric and oceanic circulations, nature of land coverings (forests, deserts, glaciers), along with the amount of CO_2 and water vapor in the atmosphere.

Briefly, then, we may conclude that the markedly varying climates of the past seem to have been due in the main to changes in the topographic form of the continental surfaces, the cold times coming when the lands are largest, highest, and decidedly volcanic. These conditions develop and tend to spread the glaciers to their climax, and then a reaction is brought about. The causation for the warmer interglacial climates appears to lie in the release of carbon dioxide from the surcharged oceanic waters, due to a temporary increase in the radiation from the Sun.

Life of the Pleistocene

The most interesting life of the Pleistocene is naturally the mammalian, and even though the remains of it are very fragmentary, they give a fair idea of its nature. The most striking of the Pleistocene mammals in North America were the three species of elephants and the one of mastodon. Of the elephants, the most interesting and widely distributed was the Siberian woolly mammoth (*Elephas primigenius*, Fig. 147, C), an animal of the cold climate, standing about 9 feet tall at the shoulders, and covered with thick under wool and long hair, which are often found preserved with the frozen carcasses in Siberia and Alaska. Coming to North America by way of Alaska, it ranged from the far north through British Columbia into the United States and across to the Atlantic coast. The mammoth also migrated from Asia into Europe and was there hunted by Pleistocene man, who engraved its picture on bone and ivory and painted it on the walls of caves (see Fig. 157).

The huge imperial mammoth (*Elephas imperator*) was probably more nearly hairless, like the modern elephants. It is less well known than the others, but its remains show an animal standing some 13 feet high — the largest of the proboscideans (Fig. 147, B). It was probably a plains animal that survived from Pliocene times and died out in the middle Pleistocene. Its known range was western America from Nebraska to Mexico City.

The Columbian mammoth (*E. columbi*) was intermediate between the other two in size, reaching a height of 10½ feet (Fig. 147, D). It was also between the two in time, succeeding the imperial mammoth and being in turn replaced by the woolly one. It roamed over the whole United States and the high plains of Mexico.

The horses were exceedingly numerous in the earlier Pleistocene, and roamed, apparently in great herds, all over Mexico and the United States and even into Alaska. There were at least ten species of *Equus*, one no larger than the smallest pony, others larger than the heaviest modern draft-horses. They were descendants of American Pliocene horses, and all died out during the Pleistocene.

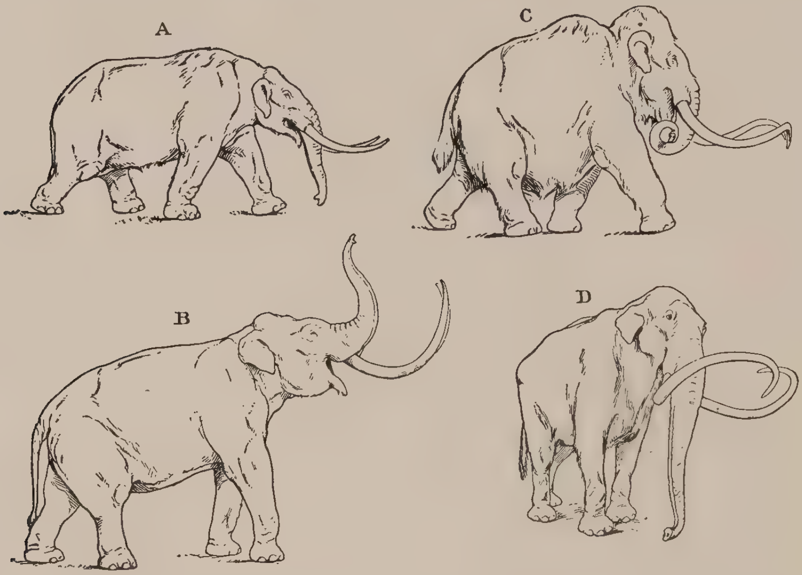


Fig. 147. — The American Pleistocene proboscideans. A, American mastodon (*Mammut americanum*). B, imperial mammoth (*Elephas imperator*). C, woolly mammoth (*E. primigenius*). After Osborn. D, Columbian mammoth (*E. columbi*). From Scott's *History of Land Mammals* (Macmillan).

Of peccaries there was an abundance, and there were also camels and llamas. During the times of glaciation the caribou ranged south into Pennsylvania and musk-oxen into Utah, Arkansas, and Ohio. The modern moose was present in the western half of the continent, but the stag-moose (*Cervalces scotti*) was a late arrival during the last ice invasion. Other ruminants related to the musk-ox occurred earlier in the period, and of bison there were at least seven kinds, ranging from Florida to Alaska, one species, *Bison latifrons*, with a horn spread of 6 feet.

Among the carnivores, the most formidable was the great sabre-tooth tiger *Smilodon* (see Fig. 148), which lived over the greater part of the United States. Of rodents the most interesting was the late Pleistocene giant beaver (*Castoroides ohioensis*), as large as a black bear.

The ground sloths were represented by a large and widely spread form, *Megalonyx*, discovered and named by President Thomas Jefferson.

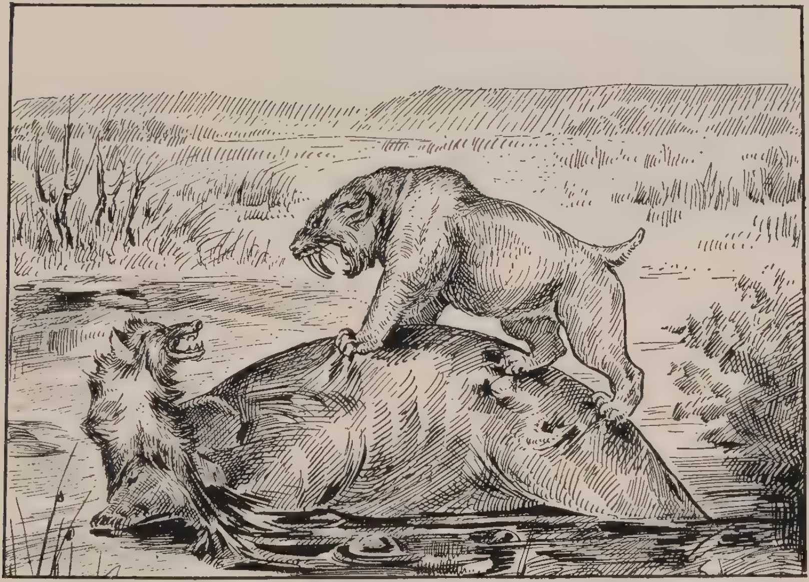


FIG. 148. — Restoration of the Pleistocene petroleum or asphalt pool at Rancho La Brea, near Los Angeles, California. The picture shows the sabre-tooth tiger (*Smilodon californicus*) standing on the carcass of an elephant (*Elephas columbi*) which has been trapped in the sticky asphalt, and snarling at a giant wolf (*Canis dirus*). Redrawn from the frontispiece of Scott's *History of Land Mammals* (Macmillan).

The giant southern form, *Megatherium* (Fig. 134), had a body as large as that of an elephant, though shorter in limb, while the oldest and smallest of the sloths was *Mylodon*.

The present-day fauna is probably richer in numbers than that of the Pleistocene, but that it is richer in kinds is doubtful, our fauna today north of Mexico having 29 families as against 37 in the still imperfectly known Pleistocene. New forms from other countries did, it is true, come to take the places of those that were dying out, but the latter included, as one authority has said, " some of the noblest animals that have graced the face of the Earth" (see Figs. 149, 150).

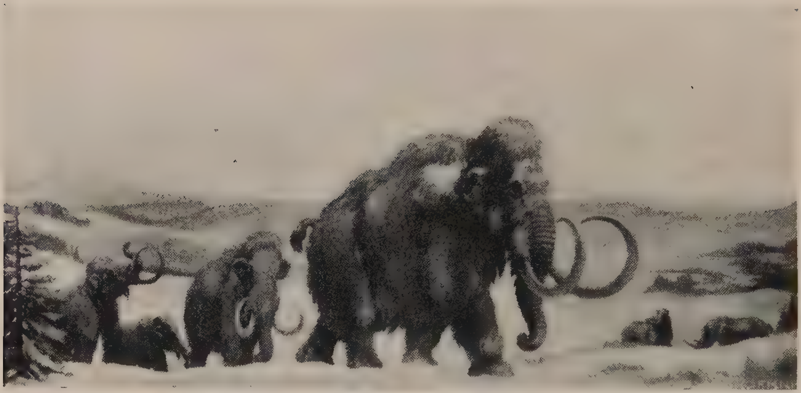


Fig. 149. — The woolly mammoth (*Elephas primigenius*), which roamed widely over the glaciated areas of North America, Europe, and Asia in the Pleistocene. Painted by Charles R. Knight for the Field Museum of Natural History, Chicago.

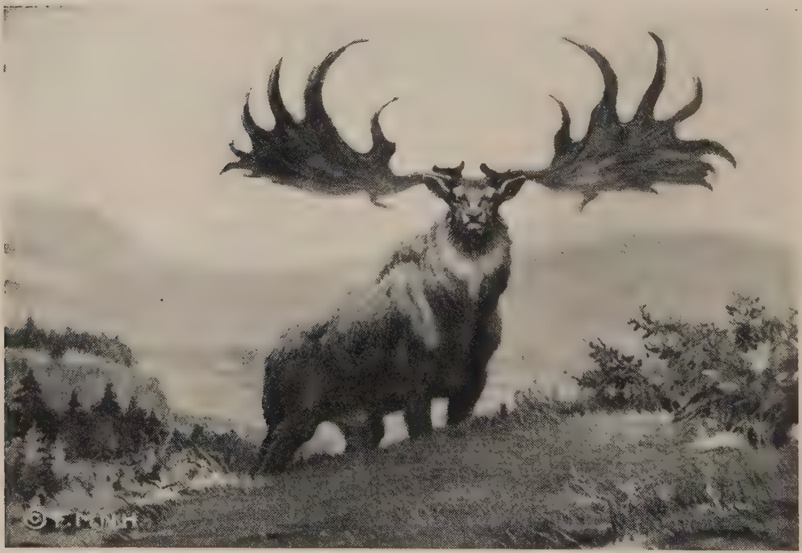


Fig. 150. — The great Irish deer (*Cervus megaceros*) of the Pleistocene of western Europe, exterminated by man in the fourteenth century. Antlers having a spread of 12 feet are known, and the top of the head was probably carried 10 feet above the ground. Painted by Charles R. Knight for the Field Museum of Natural History, Chicago.

CHAPTER XXI

MAN'S PLACE IN NATURE

> "Man is the paragon of animals, the climax of evolution."
>
> CONKLIN.

The title of this chapter is the same as that of one of Huxley's famous books, in which he states: " The question of questions for mankind — the problem which underlies all others, and is more deeply interesting than any other — is the ascertainment of the place which Man occupies in nature and of his relations to the universe of things." Some of us may not be inclined to study man as a part of nature, but whatever our prejudices, man's physical welfare and intellectual uplift into ever higher and higher states of civilization are unquestionably bound up with the ascertaining of his relations to the rest of nature.

Comparisons Between Man and the Other Primates. — Man seems to us so very different from all the animals that we can not believe him to be related to them at all, and prefer to regard him as standing isolated and alone, something quite apart from all other organisms. When, however, we begin to study his body and compare it, organ by organ, with that of other animals, we see that his isolation disappears, and that it is the thick veil of civilization in which he has so completely hidden himself that misleads us regarding his true position in the animal kingdom.

Linnæus (1707–1778), the founder of systematic Zoölogy, in his classification of animals placed man at the head of the highest group of vertebrates, the primates (from the Latin *primus*, first). The most primitive primates are the lemurs, and the higher ones are the anthropoids (means *man-like*), in which the brain is more highly developed than in any other animals. The latter division includes the monkeys, baboons, mandrills, macaques, gibbons, apes, and man.

Structurally, man and the other anthropoids are very similar, the skeletal differences being due to man's more erect posture and his changed mode of living. The erect posture of man is of ancient origin, for it is fully developed in the oldest fossil men, and probably had its beginning in the gibbons of Pliocene time. It is not, however, so much in his posture that man differs from the other large anthropoids as in

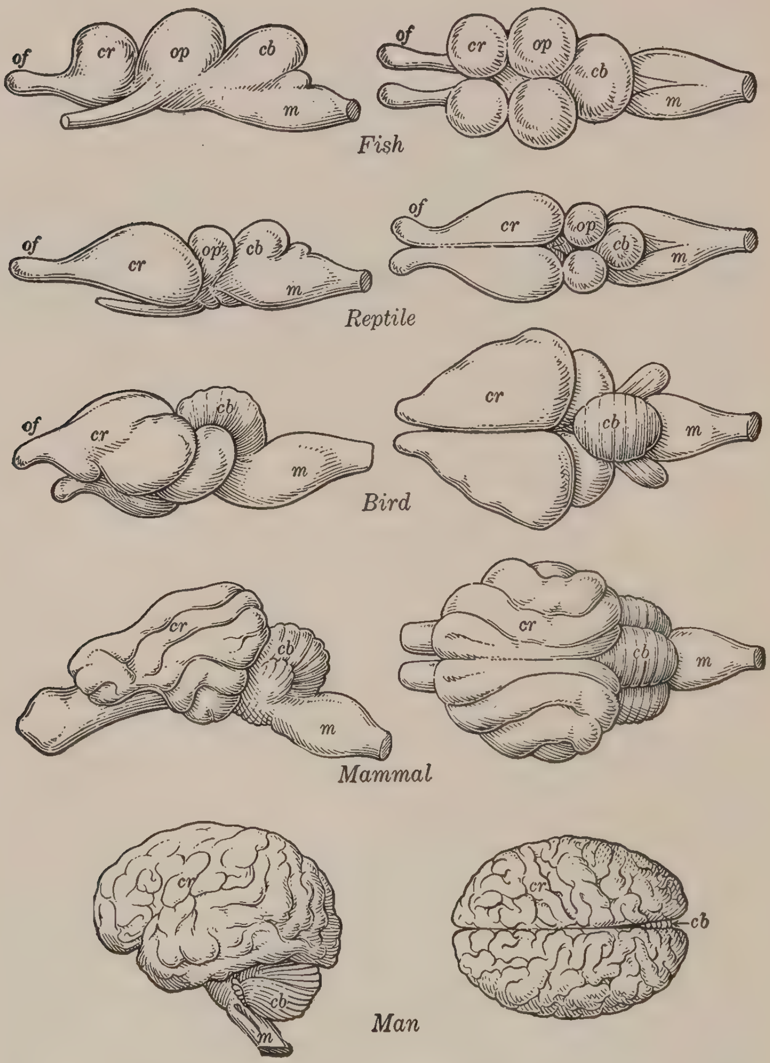


Fig. 151. — A comparison of the brains of vertebrates. cb, cerebellum; cr, cerebrum; m, medulla; of, olfactory lobe; op, optic lobe. From Shimer's *Evolution and Man.* Reprinted by permission of Ginn and Company.

his manner of progression. The larger apes spend the major portion of their time in the trees, and their strong fore limbs are especially adapted for swinging from branch to branch. Man, on the other hand, is adapted to living on the ground, " an adaptation which allowed him to escape beyond the limits of forests and occupy the whole world." This change of habitat resulted in a relative shortening of the fore limbs and a greater development of the legs, which now bore all the weight of the body. Moreover, since the human type of leg and foot is already present in the oldest known fossil man, it is clear that this evolution also took place prior to the Pleistocene. The human type of leg and foot was, then, developed long before the human brain came to be as we see it now. The large brain of man appears, in fact, to be his latest acquisition; his foot, leg, and gait are older, his size of body older still, and his erect posture quite an ancient character.

The brain of the higher vertebrates consists of two main parts, a lower and hinder division known as the cerebellum, and an upper part, the cerebrum, that is again divided into right and left hemispheres (Fig. 151). In the mammals previous to the Oligocene the lower brain is the larger, but beginning with this time the upper brain, where reason and memory are located, increases rapidly in size in nearly all stocks and finally is considerably greater than the entire cerebellum, and almost covers it.

The brain in the earliest primates has a volume in round numbers of about 100 cubic centimeters. In the great apes of the Miocene the brain ranges between 300 cc. and 600 cc., and in the early Pleistocene primitive man had a brain that varied between 940 cc. (*Pithecanthropus*) and 1300 cc. Living men have brains of between 1300 cc. and 1500 cc., with the larger ones among the most progressive peoples. (Fig. 152.)

In man the size of the brain depends to a certain extent upon the bulk of the body; tall men on the average have larger brains than small men. In women, due to their smaller size, the brain is about 12 per cent lighter than in man.

In the smallest gorilla the brain weighs 15 ounces and in the largest 20 ounces, while the weight of the entire body at maturity varies between 200 and 360 pounds. At birth the human brain weighs between 10 and 11 ounces, or about one-fifth its size at maturity. Maximum size of the brain in man is reached at about the twentieth year, and it then slowly loses weight into old age.

" Identical in the physical processes by which he originates — identical in the early stages of his formation — identical in the mode of his nutrition before and after birth, with the animals which lie immediately below him in the scale — Man, if his adult and perfect structure be compared with theirs, exhibits, as might be expected, a marvelous likeness of organization. . . . A century of anatomical research brings us back to [Linnæus'] conclusion, that Man is a member of the same order as the apes " (Huxley).

EVOLUTION OF THE PRIMATES

The geologic history of the order Primates is scanty, and not at all so complete as that of the horses, camels, and elephants. The evidence of human evolution, however, is constantly being added to and grows ever more detailed as time goes on. Moreover, all the studies that have been made of the anatomy of man and his nearest animal relatives have but added stronger evidence for his evolution, and the paleontologic evidence corroborates it and brings out, in addition, features that could not be seen in the living species considered by itself.

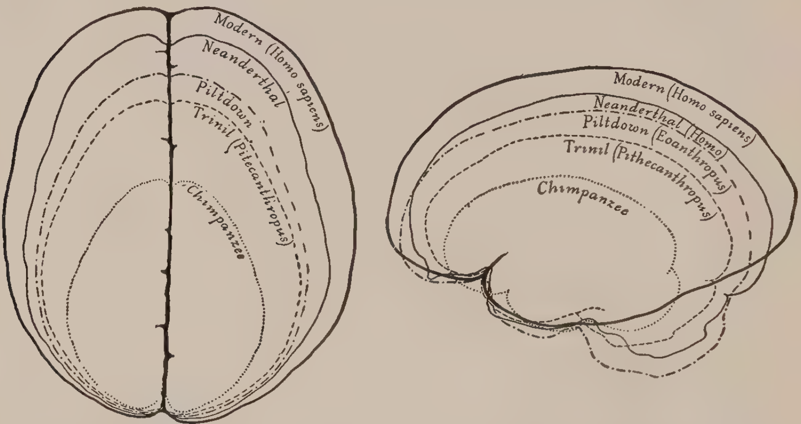


FIG. 152. — Diagrams from the top and side of the brains of chimpanzee and ancient and modern man, showing in outline their relative shapes and sizes. From Osborn's *Men of the Old Stone Age* (Scribner's).

All of the older fossil primates appear to have been tree-dwellers, and this is especially true of the living forms other than the baboons, macaques, and man. Of the living primates, all of which are tropical in distribution, the forms that live in the trees, like the lemurs or half-monkeys, the monkeys, gibbons, and tailless apes, have slender limbs, long grasping fingers and toes, flexible joints, a long and often prehensile tail, and large eyes, and are quick and alert in movement. Even though man is now wholly terrestrial in habitat, his anatomy shows derivation from tree-dwelling ancestors.

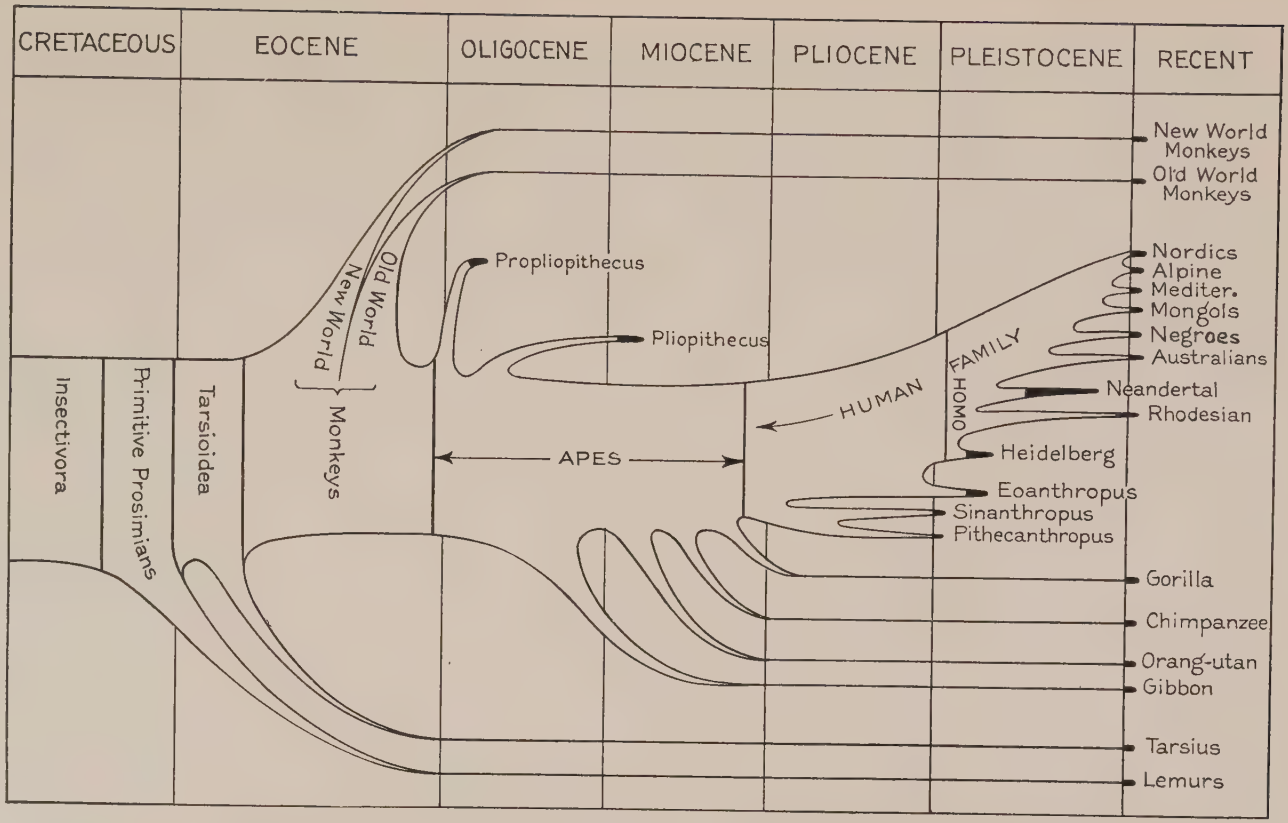


FIG. 153. — Diagram to show the relationship of the primates. Modified from Elliot Smith.

The oldest known primate-like animals occur in the basal Cenozoic deposits (Paleocene) of North America and Europe, and are intermediate between the lemurs and insectivores. True primates or primitive lemurs appear at the outset of the Eocene and continue throughout the epoch; and among them is one that may be in the direct line to man (*Tetonius* = *Anaptomorphus*, of Wyoming). In North America the primates died out with the Eocene, since no later ones are known. The history is then continued in Eurasia, Africa, and to a certain extent in South America. The African stock of the early Oligocene is ancestral to the Old World monkeys and the gibbons; and this is all that is known of the primate history in that epoch. The gibbon was probably the central stock from which the higher primates arose.

The Miocene history of the monkeys begins early in the epoch but is scanty and far-flung in Europe, India, and central Africa, and the same is true for the Pliocene of Europe, Asia, and Africa. However, apparently the Old World monkeys lived in the warmer countries of Europe, Asia, and Africa in the later Cenozoic.

The tailless apes are known in fragmentary material, mostly jaws, as far back as the middle Miocene of Europe, appearing also in the late Miocene of India and in the Pliocene of that country and Europe. *Sivapithecus* of the early Pliocene of India makes a certain definite approach to the jaw characters of man, and it may have been this stock that gave origin to the tailless apes and the human line. But the animal that interests us most here is a fossil ape discovered in South Africa in 1925, near the western border of the Transvaal at Taungs. The specimen is a remarkably well preserved skull and jaw of a young adult ape that has been named *Australopithecus*. It was found in a cave deposit (travertine) along with abundant remains of an extinct type of baboon and other fossil forms. The age of the deposit is certainly Pliocene and possibly early Pleistocene. *Australopithecus* is the most advanced anthropoid ape thus far discovered, a form intermediate between the highest living anthropoids and the most primitive known human being, *Pithecanthropus*. It is " truly man-like ape, an ape living like man away from the tropics and the forest, in a temperate region, in caves looking out over plains, swift of foot, dexterous of hand, and subsisting on the fruits of capture and the chase." No living ape is so man-like, and the genus appears to be directly in line with the human stock. We may expect the members of this stock to be found in Pliocene strata of either Asia or Africa. Man is as yet not known either by artifacts or by bones until toward the close of the Pliocene.

TABLE OF HUMAN CHRONOLOGY

North American glacial and interglacial times	European glacial and interglacial times	Duration in thousands of years. After Leverett	Cultural stages. After MacCurdy		Fossil men	
RECENT TIME Retreat of continental glaciers to present condition		25		Iron Age Bronze Age	*Homo sapiens*	
				Neolithic or New Stone Age		
				Mesolithic Age		Azilian
			Paleolithic or Old Stone Age	Magdalenian Solutrean Aurignacian		Crô-Magnon races
Wisconsin glacial	2d Würm advance Laufen retreat (warm) 1st Würm advance	75				
Fourth warm		25		Mousterian	*Homo neandertalensis*	
Iowan glacial		30				
Third warm	Riss-Würm warm	25			Grimaldi	
Illinoian glacial	Riss glacial	45				
Second warm	Mindel-Riss warm	325		Acheulian	*Paleanthropus heidelbergensis*	
Kansan glacial	Mindel glacial	75				
First warm	Günz-Mindel warm	325		Chellean Pre-Chellean	*Eoanthropus* *Sinanthropus* *Pithecanthropus*	
Nebraskan glacial	Günz glacial	75	Eolithic	Cromerian		
Pliocene epoch				Foxhallian Ipswichian		

EOLITHIC IMPLEMENTS

In many places have been found large and small stones, chiefly of flint, that have rudely chipped edges and resemble weapons made by primitive man. These are known as *eoliths*, " dawn stones." There is now no doubt about man-made eoliths and evidence of man-made fires occurring in the upper Pliocene strata of southeastern England (East Anglia). Younger eoliths, of the First Glacial time, occur at Cromer, Norfolk. These implements are older than the oldest known human bones, and older than the paleoliths of the Old Stone Age.

Fifty years ago there was found in the Coralline Crag beds (late Pliocene) of East Anglia a stiletto made of a deer antler, and Foxhall in 1888 yielded a well made flint implement. Since then Reid Moir has made similar finds here, and more implements have been secured out of the Cromer Forest bed.

Men of the Old Stone Age (Paleolithic)

The time of the Old Stone Age is that of the Pleistocene epoch. Everywhere the men of this time were fierce hunters and makers of stone implements.

Paleolithic Implements. — The oldest *well made* human implements are known as *paleoliths,* and among these the older ones are very crude in workmanship (Fig. 154). They are nodules of flint, flaked to the required shape and size by means of oblique blows delivered to the right and left. For the greater part they are rude scrapers and knives. Although none of them appear to be weapons of the chase, their makers, the men of the Old Stone Age, were undoubtedly learning how to hunt animals for food and how to defend themselves by their greater skill in the invention and use of improved killing devices.

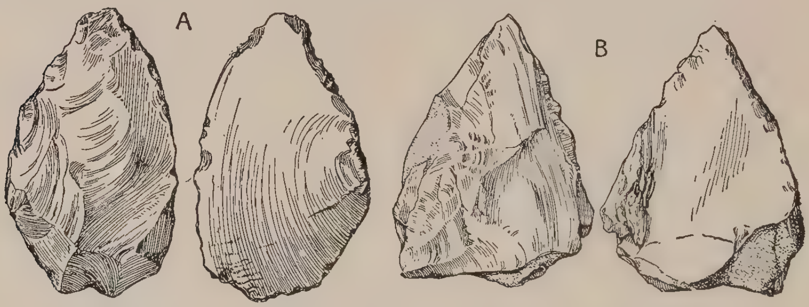


Fig. 154. — Two primitive Paleolithic flint implements associated with *Eoanthropus.* Each shows a coarsely flaked face and a simply flaked face. After Woodward, from British Museum Guide.

A human chronology based on the state of the stone and metal cultures can be expressive of a correct human progression in tool making only when viewed in a broad way. The more effective weapons made of iron are known to be of younger time than those of copper, and in the same way Neolithic ones are found later than Mesolithic and Paleolithic types; nevertheless, the stage of culture in a given place does not necessarily correlate with the same stage elsewhere. For example, when the English with their iron weapons invaded Tasmania, they found the natives still using Paleolithic implements, while the North

American Indians had tools of a far better type (Neolithic), and their discoverers had advanced into a high stage of civilization. Therefore, long after some of the ancient hunters were making paleoliths, others undoubtedly remained in the Eolithic stage. The makers of paleoliths also learned to make implements and ornaments out of bone and horn.

Java Man. — The oldest known remains of fossil man himself were discovered in 1891 at Trinil, Java, together with those of many kinds of animals which are now extinct in that region. The geologic age of the fossils is somewhat uncertain, but the man of Trinil is thought to have lived during the earliest Pleistocene; as Java then as now lay in the tropics, the climate here was mild to warm.

The human remains consist of the upper part of the skull, or cranial vault, three molar teeth, and the entire left femur. Dubois, the discoverer, named this human being *Pithecanthropus erectus*, which means *the ape-man who walked erect* (Fig. 155). The skull is of the long-headed type, and has a low crown with prominent brow-ridges, the forehead is more receding than that of the chimpanzee, and the volume of the brain cavity is approximately 940 cc. *Pithecanthropus* is estimated to have stood 5 feet 6 inches high. In his mental evolution he had risen far higher than halfway between the apes and modern man, and must be included in the human family. He is probably not in the direct line to the higher types of man, but represents a specialized and unprogressive branch which became extinct in the older Pleistocene.

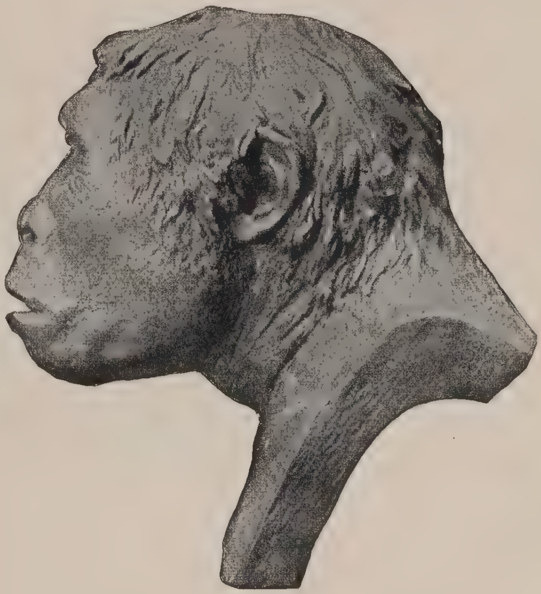


Fig. 155. — Profile view of head of *Pithecanthropus*, the Java ape-man, after a model by J. H. McGregor. From Osborn's *Men of the Old Stone Age* (Scribner's).

Peking Man. — Late in 1928, there was found deeply buried in a cave deposit of travertine that occurs in Ordovician limestone at Chou Kou Tien, southwest of Peking, China, the entire uncrushed top of a skull of a young adult female, now known as *Sinanthropus pekingensis*. It is the only complete and uncrushed skull so far recovered among the older fossils in the human line, but the facial bones are missing and as yet the brain-case is not cleared of its travertine. Later reports say that another skull of an adult male has been found, with the bones of the face and jaw preserved; this male shows that the canines are no longer than the other teeth, though slightly heavier than in living man. At the same locality have also been recovered, in earlier diggings, parts of jaws and skull fragments, along with an abundance of isolated teeth.

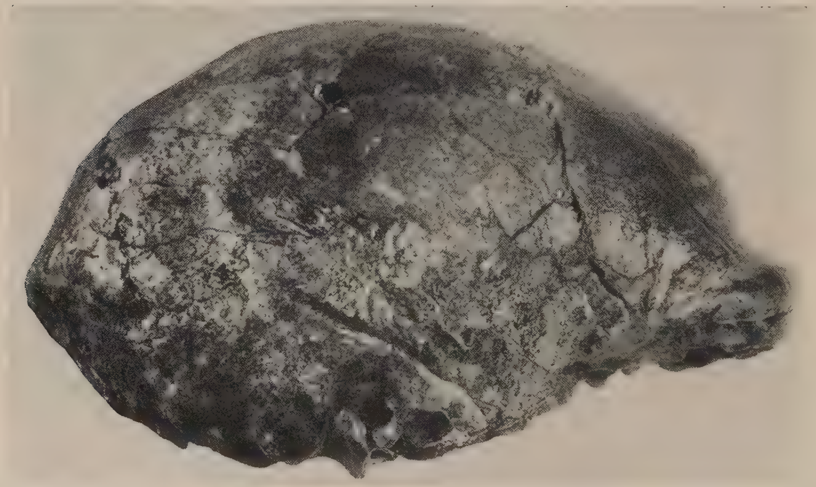


Fig. 156. — Top of skull of Peking man (*Sinanthropus pekingensis*), showing the low receding forehead and the massive brow-ridges. Photograph from Davidson Black.

All in all, the remains are among the most important of those of ancestral man, and all the more valuable because they are from an area in which early man was previously unknown though looked for. The travertine also has an abundance of extinct mammals, among them a rhinoceros and a short-tailed monkey (*Macacus*). No implements of any kind, or evidence of fire or burial, or skeletal parts other than of the head have been found. The age of the deposit is clearly Pleistocene, and apparently very early in this epoch.

The skull of *Sinanthropus*, or Peking man, according to Professor Davidson Black of Peking University, is remarkable for its massive brow-ridges and low receding forehead. Its length is about that of *Pithecanthropus*, to which it is probably closest in relationship, but it has a greater posterior height and therefore a larger brain capacity. In the latter feature it is closer to *Eoanthropus*, but otherwise much more primitive. The skull preserves both jaw sockets, a circumstance that will allow of a definite restoration. Upon the whole, the skull of *Sinanthropus* appears to be morphologically nearest to *Pithecanthropus*, but larger in brain, and much more archaic than the brainier Neandertal man. Certain features (tympanic area) recall those of the chimpanzee; the jaws are apelike, but the teeth are human. In other words, *Sinanthropus*, though relatively large in brain, is far more ancient in structure than the Neandertal man, but of the line that gave rise to the latter and *Homo sapiens*. In the Java man, the brain in size was " just reaching the threshold of a human standard," *i.e.*, 940 cc., whereas in Peking man it is " only a little larger," and probably not so large as in Piltdown man (1260 cc.) (Keith). (See Fig. 156.)

"The three widely differentiated genera of Early Pleistocene man found respectively in Java, England, and China represent the scattered descendants of ancestors who had already been wandering east and west throughout the vast Euroasiatic continent for hundreds of thousands of years before any one of the three genera left the skulls in the places where they have recently been found " (Elliot Smith).

Piltdown Man. — The oldest known remains of the human family in Europe, the " dawn man " or *Eoanthropus*, were found in 1913 in the plateau gravels at Piltdown, Sussex, England. The fragments, which include important parts of a skull and jaw, have been carefully set together and the entire head restored by Smith Woodward, Keith, and Elliot Smith, the three foremost British authorities. The lower part of the face is decidedly prognathous or " snouty," the forehead, though narrow, is not receding, and is as steep as in modern man, the brow-ridges are feeble, and the brain-case is very thick, with a capacity of 1260 cc. The size of the brain, therefore, compares favorably with that of the average European, which has a capacity of about 1500 cc. The skull, which is thought to be that of a female, is low in proportion to length, and even though it is archaic, is truly human; but the chinless lower jaw, with its large canines, is distinctly simian and very much like that of a young chimpanzee. This strange creature, therefore, combines a human brain-case with an ape's jaw. It was probably able to speak, though in a rudimentary fashion.

Eoanthropus was a human brute, hunting and defending himself mainly with his fearful biting mouth. He was still a primitive slayer, though keener than any of his animal associates.

With *Eoanthropus* were associated very ancient types of Paleolithic implements (Fig. 154). The plateau gravels in which the " dawn man " occurs are thought to be of the first interglacial warm time, when the hippopotamus lived in England.

Heidelberg Man. — In 1907, at Mauer, Germany, not far from

Heidelberg, there was found a well preserved human jaw with all of the teeth. It was buried about 80 feet beneath the surface in river-deposited sand of early middle Pleistocene age and possibly of the second interglacial warm time. More recently eoliths have been found in the same stratum that held the jaw. The teeth, while powerful, are distinctly like those in modern man, *Homo sapiens*, but the jaw bone is massive and broad and clearly like that of an anthropoid ape. This man, known as *Homo* (*Paleanthropus*) *heidelbergensis*, had a more pronounced type of chin than is found in the older jaws.

Neandertal Man. — In 1856 most interesting human remains were found in the little valley known as the Neandertal, lying between Düsseldorf and Elberfeld, Germany. Since then, several entire skeletons have been recovered, and remains of many men, women, and children of this Neandertal race have been found in caves and rock shelters in Belgium, France, Gibraltar, and Croatia. Their implements, moreover, are found scattered throughout western Europe and eastward into Poland, the Crimea, and Asia Minor. It is quite likely that the race ranged over Asia and Africa. In France these people are known as the Mousterians, and they are thought to have been the first who dwelt in caves. They appeared during the Riss-Würm interglacial time and lived through the first Würm glacial advance, a time estimated to be anywhere from 60,000 to 100,000 years ago. It was in the main the time of the bison, horse, reindeer, and mammoth, on all of which the Neandertal men subsisted. The race lived for a long time geologically.

The Neandertal people (*Homo primigenius*) were a savage-looking race of stout build, averaging about 5 feet 3 or 4 inches, with legs slightly bent at the knee, and with disproportionately large heads, set forward on the shoulders. The head was characterized by the low broad brain-case, receding forehead, very prominent brow-ridges, low wide nose, prominent jaws, and broad receding chin very like that of Heidelberg man but not quite so massive. The back was less erect, the double curve of the backbone not being complete as in modern man. These skeletal characters all approach those of the higher apes. The brain-case, however, although not so large beneath the forehead, was nevertheless capacious (1400–1600 cc.), large in the back and lower part. " It has been inferred from its proportions that the species was deficient in the higher qualities of reasoning and association and probably less capable of social organization." (Matthew.)

The Neandertals made fairly good stone implements and also knew how to kindle a fire, for hearths occur in their cave abodes. In at least two cases the skeletons were found in their original burial places, and were laid away with their implements, paints, and food, indicating a ceremonial interment and offerings to assist the departed in the spirit world.

Aurignacian Man. — The older Neandertal men of western Europe lived under a mild and winterless climate (Riss-Würm interglacial), and the oncoming last glacial time (first Würm ice advance) brought on changed and much harder conditions; out of the struggle with the environment and a new human invasion finally came (during the milder Laufen interglacial time) the dominancy of the Aurignacian men with better brains, in other words, primitive *Homo sapiens*, one of the three Crô-Magnon races.

The Aurignacians remained hunters, but had far greater skill in the making of stone and bone implements than did their predecessors, the Neandertals, with whom they amalgamated. They appeared in western Europe at about the close of the Glacial Period, or about 30,000 to 40,000 years ago. They came from the east, spreading westward from Asia Minor, and their remains are found throughout the greater part of western and central Europe and most of the Mediterranean countries.

The Aurignacian races appeared throughout Europe at a time when the climate was colder than it is now. They knew how to make fire but had no domestic animals or plants. The animals of the chase then living were largely the reindeer and horse, and the time is also spoken of as the epoch of the reindeer. The Aurignacian implements are of the late Paleolithic type, but the workmanship of the flints is better and constantly improves with time, and the race had many more kinds of tools to serve more purposes. They also used bone for awls and ivory for skewers and ornaments, and made spears, bows and arrows, and fur garments. Themselves they ornamented with marine snail shells derived from the Mediterranean and the Atlantic, with fossil shells from far inland places, with teeth of mammals, and even with those of human beings, and later with beads, bracelets, and other objects manufactured out of shell and ivory.

Armed with better weapons of the chase and a wider knowledge of their use, the Aurignacians were able to take better advantage of their environment. Under these circumstances, they had more ease and time for reflection, and we witness in them the birth of bodily adornment, clothing, and the fine arts. Their achievements along these lines excite the wonder and admiration of all anthropologists. Sculpture and drawing appear almost simultaneously, and later comes painting. This art we find preserved in the caves of France and Spain (see Fig. 157).

Magdalenian and Later Races. — The Aurignacians were followed by other Crô-Magnon races, the Solutreans and Magdalenians, whose history goes back perhaps 20,000 to 30,000 years, earlier than the most ancient monuments of Egypt or Chaldea. They, too, were hunters, lived in wigwams, and herded cattle, sheep, and goats; and somewhere about this time began the farming of plants for food.

Mesolithic and Neolithic Cultures

During the latest part of Pleistocene time, the climate moderated and became moister throughout Europe, and early in Recent time the Magdalenian people changed into the Azilians, the makers of Mesolithic implements. With the climatic change, the reindeer, the main source of food and clothing for the Crô-Magnon races, vanished from all of southern Europe and retreated farther and farther northward as the continental glaciers melted away. Man also spread northward, following the reindeer, arriving in Denmark about 12,000 B.C., and in Sweden about two thousand years later.

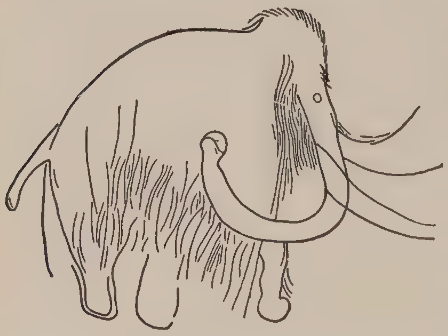


Fig. 157. — Painting of mammoth on cave wall at Combarelles, France. From George Grant MacCurdy.

The people of southern Europe, on the other hand, developed the culture known as Neolithic, and the New Stone Age had dawned. The tools, made of flint, were now of the highest excellence, and in addition, many of the weapons and tools were rubbed into shape and polished. In Neolithic and Mesolithic times, next to food and clothing, the most important object to the men of the New Stone Age was flint. Flint mines were to them what iron mines are to us.

The people of the New Stone Age began to make pottery and introduced the herding of cattle and communal life. Later on, permanent habitations in stone huts and skin wigwams, along with agriculture, became more general, and their pottery was made more and more on the potter's wheel. Finally the metals copper, gold, and iron were introduced. Definite migrations and warfare began also with these people, and manufacturing and trading as well.

Human civilization began roughly about 18,000 B.C. in Asia Minor, Arabia, and Persia. The Neolithic people of the city of Susa, Persia, appear to go back to 16,000 B.C., and the mid-sea peoples of Crete in the eastern Mediterranean to about 12,000 B.C. The stone implements found in the desert on either side of the Nile indicate man's presence here for at least 17,000 years.

Man in North America. — Many times during the past fifty years have the remains of fossil man been found in such geological associations as to lead their discoverers to assert the presence of man in North America, if not actually in the Pleistocene, at least in strata some thousands of years in age. In the past few years, however, it has been demonstrated that human remains occur in the Pleistocene.

Mexican archeologists and geologists have long been calling attention to the occurrence of skeletons of man and something of his culture buried beneath from 15 to 30 feet of lava at San Angel, a southern suburb of the City of Mexico. These lava flows are believed to have taken place not less than 2000 years ago and the lower one may have occurred even 10,000 years ago. To the northwest of the same city the identical culture is found beneath from 10 to 12 feet of sediments. The Aztec culture, on the other hand, is modern, since it occurs above the two lava flows and in the soil. The history of the Aztec peoples is dated back to 100 B.C. and less well known back to 500 B.C.

In 1916, human remains were found along with bits of pottery and charcoal at Vero on the Atlantic coast of Florida. Since then much more human material and many additional artifacts have been discovered here and 40 miles to the north at Melbourne. The associated plants, though of living species, appear to indicate that the man of Vero may be but a few tens of thousands of years old. The associated mammal bones are all of extinct Pleistocene forms (among them is the Columbian elephant), and presumably are of a warm climate.

Still other evidence appears to place beyond doubt the probability that the mound-building Indians and the cold-climate mastodons and elephants lived together in North America something like 10,000 years ago. On the basis of the annually layered brick clays of the Hudson and Connecticut valleys, it would appear that this time dates back somewhere between 10,000 and 5000 years.

At Colorado, Texas, beneath 18 feet of Pleistocene gravels, was found an extinct buffalo of the Asiatic type, and beneath the skeleton were three stone implements of the chase. In the same layer occur other extinct Pleistocene mammals. Similar finds have been made in stream-gravel terraces in Oklahoma, and others in Kansas, but the most remarkable discovery of all has recently been made at Folsom, New Mexico. Here after three years of excavation there have been disinterred from forty to fifty skeletons of the extinct *Bison taylori*, which are evidently the remains of an ancient meat kill, since beneath the bones or among them were sixteen arrowheads. Surely we now have the evidence that *Homo sapiens* was present in North America some 10,000 or more years ago.

RÉSUMÉ

We have seen that the ape-man *Pithecanthropus* of Java and the somewhat younger *Sinanthropus* of China were in existence in the earliest Pleistocene, a time now estimated by geologists to be somewhere between 1,000,000 and 2,000,000 years ago. As the true eoliths, however, are of human workmanship, they are evidence of man's greater antiquity in western Europe, where he has been since late in Pliocene time.

In early middle Pleistocene deposits, human bones are again in evidence, first in the dawn man (*Eoanthropus*) of England, who is not in direct ancestry with the men of the present, and secondly in Germany in Heidelberg man, thought to be in the direct line with living men (*Homo sapiens*). Much more recent than either of these ancestral men are the Neandertal people, who may not be directly related to *Homo sapiens*. They made their appearance probably 100,000 years ago and lived almost into modern times. As early as late Pliocene time, man in England knew how to kindle fire. The Neandertal men also made fires, and had a religious instinct. With the appearance of the Aurignacians, 30,000 to 40,000 years ago, modern men are at hand, while human society and primitive farming had their rise about 10,000 years ago.

THE FUTURE

The long geologic history of the Earth reveals no beginning and certainly no cataclysm greater than the " critical times " between the eras. In other words, while former grand dynasties of plants and animals are gone, or have evolved into something different, life in vast variety has been continuous since at least the beginning of the Paleozoic or during some 500 million years. Astronomers and physicists tell us that the Sun has enough radiating energy to last for many billions of years more, and, barring another star approach, for which there is not the slightest present evidence in our galaxy, humanity at least is assured of a future far longer than his past record, and with no worse climatic conditions than the Earth has already passed through. Climatic changes tending toward an amelioration of present conditions are bound to come, and in the smaller sharp changes lies the possibility of cataclysmic disease through micro-life, with possible human disaster, but all this can be guarded against if man is sufficiently careful in developing races ever better mentally, with higher ideals for the common good.

Envoi

The serious student who has come thus far must see clearly that nature through the process called evolution has done everything for man, giving him his very usable body and his wonderful brain, and thus making it possible for him to adapt himself to almost all conditions of life open to the higher organic types. But now that humanity has attained maturity, and man possesses a great body of knowledge that tells him how to control his environment, and through it the future welfare of his body physiological and the body politic, the question arises: Will he use this knowledge? It is now in the keeping of the few, mainly the philosophical biologists and the medical men, who are, however, ever ready to pass it on to those who want to know. But can our system of education ever be extended to most of the young of the masses of humanity? Will they, moreover, appreciate the keeping of what has been given them, and what is more, ever advance the garnering of truth through experience and trial and error, so that man may evolve into superman?

We must of course adapt our civilization to the needs and wants of our bodies to keep them fit, and working to best advantage under nature's environment, but all this must be under the control of the garnered knowledge of the wise men, so that our brain — the seat of our soul — may ever attain to greater individual and societal perfection.

Evolution as seen through the geological ages teaches plainly that we can not remain where we are, for in nature nothing is constant but change: we either must retrogress, or even degenerate out of existence as have many former organic dynasties, or we must advance, not so much in bodily perfection or in our societal life, as in a better brain, in more knowledge and spirituality. Hence each generation must give its own answer — and it is our prayer that this answer will ever be a better one — to the greatest riddle of life: Why are we here?

COLLATERAL READING

CHAPTER II: GEOLOGIC TIME-TABLE

Sir Archibald Geikie, The Founders of Geology, 2d ed., 1905. Macmillan.

G. P. Merrill, One Hundred Years of American Geology, 1924. Yale University Press.

K. A. von Zittel, History of Geology and Paleontology, 1901. Scribner's.

Joseph Barrell, Rhythms and the Measurements of Geologic Time. Bulletin of the Geological Society of America, vol. 28, 1917, pp. 745–904.

Arthur Holmes, The Age of the Earth. An Introduction to Geological Ideas, 1927. Benn's Sixpenny Library, No. 102 (London).

A. C. Lane, How Old is the Earth? Scientific American, February 1930, pp. 110–113.

Charles Schuchert, The Age of the Earth on the Basis of Sediments and Life. National Research Council, Bull. 80, 1931.

CHAPTER III: FOSSILS

Childs Frick, W. D. Matthew, and others, The Romance of Fossil Hunting. Natural History, September-October, 1926.

Winifred Goldring, Handbook of Paleontology for Beginners and Amateurs. Pt. I. The Fossils. New York State Museum, Handbook 9, 1929.

CHAPTER IV: EVOLUTION

W. C. Curtis and Mary J. Guthrie, Textbook of General Zoology, 1927. Read especially Chapter 19, Genetics; Chapter 20, The Theory of Evolution; Chapter 21, The Causes of Evolution. Wiley.

Charles Darwin, The Origin of Species, 1859.

Charles Depéret, The Transformations of the Animal World, 1909. Appleton.

L. J. Henderson, The Fitness of the Environment, 1913. Macmillan.

Sir Ray Lankester, Extinct Animals, 1905. Holt.

R. S. Lull, Organic Evolution, rev. ed., 1929. Macmillan.

W. D. Matthew, Outline and General Principles of the History of Life. University of California, Syllabus Series No. 213, 1928.

M. M. Metcalf, An Outline of the Theory of Evolution, 1911. Princeton University Press.

H. J. Muller, The Method of Evolution. Scientific Monthly, December, 1929, pp. 481–505.

H. F. Osborn, The Origin and Evolution of Life, 1917. Scribner's.

L. L. Woodruff, G. H. Parker, and others, The Evolution of Earth and Man, 1929. Edited by G. A. Baitsell. Read especially Chapter 4, The Pulse of Life, by R. S. Lull; Chapter 12, The Trend of Evolution, by E. G. Conklin; and Chapter 13, The Mechanism of Evolution, by W. R. Coe. Yale University Press.

CHAPTER V: PLANTS

E. W. Berry, Tree Ancestors; a Glimpse into the Past, 1923. Williams and Wilkins.

F. H. Knowlton, Plants of the Past, 1927. Princeton University Press.

D. H. Scott, The Evolution of Plants, 1912. Holt.

CHAPTER VI: ANIMALS

E. W. Berry, Paleontology, 1929. McGraw-Hill.

W. C. Curtis and Mary J. Guthrie, Textbook of General Zoology, 1927. See especially Chapters 1 to 5 on vertebrate anatomy.

Roy L. Moodie, The Antiquity of Disease, 1923. University of Chicago Press.

H. W. Shimer, An Introduction to the Study of Fossils (Plants and Animals), 1914. Macmillan.

A. W. Weysse, A Synoptic Text-book of Zoology for Colleges and Schools, 1904. Macmillan.

L. L. Woodruff, Foundations of Biology, 1922. Macmillan.

Karl A. von Zittel–Charles R. Eastman, Text-book of Paleontology, vol. 1, Invertebrates, 2d ed., 1913; vol. 2, Fishes, Amphibians, Reptiles, Birds, 1902; vol. 3, Mammals, rev. ed., 1925.

CHAPTER VII: EARTH BEFORE GEOLOGIC TIME

C. G. Abbot, The Sun, 1911. Appleton.

Joseph Barrell, The Origin of the Earth, in "The Evolution of Earth and Man," 1929. Chapter 1, pp. 1–46. Yale University Press.

T. C. Chamberlin, The Two Solar Families, 1928. University of Chicago Press.

Sir James Jeans, The Universe around Us, 1929. Macmillan.

Harold Jeffreys, The Earth, 1924. Cambridge University Press.

Harlow Shapley and others, The Universe of Stars, 1926. Harvard Observatory.

CHAPTER VIII: ARCHEOZOIC ERA

A. P. Coleman and W. A. Parks, Elementary Geology, 1922. Dent (London and Toronto).

CHAPTER IX: PROTEROZOIC ERA

R. A. Daly, The Limeless Ocean of Pre-Cambrian Time. American Journal of Science, 4th series, vol. 23, 1907, pp. 93–115.

C. D. Walcott, Abrupt Appearance of the Cambrian Fauna on the North American Continent. Smithsonian Miscellaneous Collections, vol. 57, 1910, pp. 1–16.

C. D. Walcott, Evidences of Primitive Life. Annual Report of the Smithsonian Institution for 1915, 1916, pp. 235–255.

CHAPTER X: PALEOGEOGRAPHY

Th. Arldt, Handbuch der Palaeogeographie, 1919–1922. Borntraeger (Leipzig).

E. Dacqué, Grundlagen und Methoden der Paläogeographie, 1915. Fischer (Jena).

A. de Lapparent, Traité de Géologie, 5th ed., 1906. (For world maps.) Masson (Paris).

Charles Schuchert, Paleogeography of North America. Bulletin of the Geological Society of America, vol. 20, 1910, pp. 427–606.

Charles Schuchert, Sites and Nature of the North American Geosynclines. Ibid., vol. 34, 1923, pp. 151–230.

CHAPTER XI: EARLY PALEOZOIC

A. W. Grabau and H. W. Shimer, North American Index Fossils, 1909–1910. Seiler.

G. Gürich, Leitfossilien, Kambrium und Silur, 1908. Borntraeger (Berlin).

C. D. Walcott, Mount Stephen Rocks and Fossils. Canadian Alpine Journal, vol. 1, 1908, pp. 232–248.

C. D. Walcott, A Geologist's Paradise. National Geographic Magazine, vol. 22, 1911, pp. 509–521.

CHAPTER XII: MIDDLE PALEOZOIC

J. D. Dana, Corals and Coral Islands, 1872.

A. W. Grabau, Guide to the Geology and Paleontology of Niagara Falls and Vicinity. New York State Museum, Bull. 45, 1901.

A. W. Grabau and H. W. Shimer, North American Index Fossils, 1909–1910. Seiler.

G. Gürich, Leitfossilien, Devon, 1909. Borntraeger (Berlin).

E. M. Kindle and F. B. Taylor, Geologic Atlas of the United States, Niagara Folio (No. 190). United States Geological Survey, 1913.

Hugh Miller, Old Red Sandstone, 1851.

CHAPTER XIII: LATE PALEOZOIC

E. W. Berry, Paleobotany: A Sketch of the Origin and Evolution of Floras. Annual Report of the Smithsonian Institution for 1918, 1920, pp. 289–407.

A. W. Grabau and H. W. Shimer, North American Index Fossils, 1909–1910. Seiler.

G. Gürich (ed.), Leitfossilien, Karbon und Perm, and Marines Perm, 1923, 1927. Borntraeger (Berlin).

M. R. Campbell, The Coal Fields of the United States. United States Geological Survey, Professional Paper 100–A, 1917.

D. White and R. Thiessen, The Origin of Coal. United States Bureau of Mines, Bull. 38, 1913.

The Coal Resources of the World. Twelfth International Geological Congress, Canada, 1913.

World Atlas of Commercial Geology. United States Geological Survey, 1921. Coal, pp. 9–16.

CHAPTER XIV: PERMIAN

E. C. Case, The Environment of Life in the Late Paleozoic in North America. Carnegie Institution of Washington, Pub. No. 283, 1919.

A. P. Coleman, Ice Ages Recent and Ancient, 1926. Macmillan.

Roy L. Moodie, The Coal Measures Amphibia of North America. Carnegie Institution of Washington, Pub. 238, 1916.

Charles Schuchert, Review of the Late Paleozoic Formations and Faunas, with Special Reference to the Ice-age of Middle Permian Time. Bulletin of the Geological Society of America, vol. 39, 1928, pp. 769–886.

CHAPTER XV: EARLY MESOZOIC

Joseph Barrell, Central Connecticut in the Geologic Past. Connecticut State Geological and Natural History Survey, Bull. 23, 1915.

E. W. Berry, The Jurassic Lagoons of Solenhofen. Scientific Monthly, October, 1918, pp. 361–378.

G. Gürich, Leitfossilien, Trias, 1925. Borntraeger (Berlin).

G. P. Merrill, The Fossil Forests of Arizona, 1912. Washington.

H. G. Seeley, Dragons of the Air, 1901. Appleton.

John C. Van Dyke, The Desert, 1901. Scribner's.

CHAPTER XVI: DINOSAURS AND TOOTHED BIRDS

G. Heilmann, The Origin of Birds, 1927. Appleton.

R. S. Lull, Organic Evolution, rev. ed., 1929, Chapters 30, 31. Macmillan.

R. S. Lull, Dinosaurian Climatic Response, in "Organic Adaptation to Environment" (M. R. Thorpe, ed.), 1924. Yale University Press.

W. D. Matthew, Dinosaurs, with Special Reference to the American Museum Collection. American Museum of Natural History, Handbook Series No. 5, 1915.

J. Parkinson, The Dinosaur in East Africa, 1930. Witherby (London).

CHAPTER XVII: LATE MESOZOIC

E. W. Berry, The Lower Cretaceous Floras of the World. Maryland Geological Survey, Lower Cretaceous, 1911, pp. 99–151.

Thomas Huxley, On a Piece of Chalk, 1868. Collected Essays, vol. 8, pp. 1–36.

E. W. Sinnott and I. W. Bailey, The Origin and Dispersal of Herbaceous Angiosperms. Annals of Botany, vol. 28, 1914, pp. 547–560.

T. W. Stanton, A Comparative Study of the Lower Cretaceous Formations and Faunas of the United States. Journal of Geology, vol. 5, 1897, pp. 579–624.

CHAPTER XVIII: CENOZOIC ERA

O. Abel, Grundzüge der Palaeobiologie der Wirbeltiere, 1912. Schweizerbart'sche Verlagsbuchhandlung (Stuttgart).

C. C. O'Harra, The White River Badlands. South Dakota School of Mines, Bull. 13, 1920.

R. S. Yard, The Book of the National Parks, 1919. Scribner's.

CHAPTER XIX: MAMMALS

R. Broom, On some Recent New Light on the Origin of Mammals. Proceedings of the Linnæan Society of New South Wales, vol. 54, pt. 5, 1929, pp. 688–694.

F. B. Loomis, The Evolution of the Horse, 1926. Marshall Jones.

R. S. Lull, Organic Evolution, rev. ed., 1929, Chapters 32 to 38. Macmillan.

R. S. Lull, The Evolution of the Horse Family. Peabody Museum of Natural History, Special Guide No. 1, 1931.

W. D. Matthew, Outline and General Principles of the History of Life. University of California, Syllabus Series No. 213, 1928.
H. F. Osborn, The Age of Mammals, new ed., 1921. Macmillan.
H. F. Osborn, The Extinct Giant Rhinoceros Baluchitherium of Western and Central Asia. Natural History, vol. 23, 1923, pp. 209–228.
H. F. Osborn, The Elephants and Mastodons arrive in America. Ibid., vol. 25, 1925, pp. 3–23.
H. F. Osborn, The Titanotheres of Ancient Wyoming, Dakota, and Nebraska. United States Geological Survey, Mon. 55, 1929.
W. B. Scott, A History of Land Mammals in the Western Hemisphere, 1913. Macmillan.
G. G. Simpson, American Mesozoic Mammalia. Peabody Museum of Natural History, Memoirs, vol. 3, pt. 1, 1929.

CHAPTER XX: PLEISTOCENE TIME

Ernst Antevs, Maps of the Pleistocene Glaciations. Bulletin of the Geological Society of America, vol. 40, 1929, pp. 631–720.
A. P. Coleman, Ice Ages Recent and Ancient, 1926. Macmillan.
G. F. Wright, The Ice Age in North America, 6th ed., 1920. Oberlin, Ohio.

CHAPTER XXI: MAN

E. G. Conklin, The Direction of Human Evolution, 1921. Scribner's.
W. K. Gregory, Studies on the Evolution of the Primates. Bulletin of the American Museum of Natural History, vol. 35, 1916, pp. 239–355.
W. K. Gregory, The Origin and Evolution of the Human Dentition, 1922. Williams and Wilkins.
W. K. Gregory, The Upright Position of Man: a Review of its Origin and Evolution. Proceedings of the American Philosophical Society, vol. 67, 1928, pp. 339–376.
W. K. Gregory, Our Face from Fish to Man, 1929. Putnam.
Ales Hrdlička, The Skeletal Remains of Early Man. Smithsonian Miscellaneous Collections, vol. 83, 1930.
Sir Arthur Keith, Concerning Man's Origin, 1928. Putnam.
G. G. MacCurdy, Human Origins, 1924. Appleton.
J. Reid Moir, The Antiquity of Man in East Anglia, 1927. Cambridge University Press.
G. Elliot Smith, The Evolution of Man, 1924. Oxford University Press.

INDEX

Asterisks refer to illustrations

A

Acadia, 158
Acadian Disturbance, 9, 139, 144
  faunal realm, 133
Acadic geosyncline, 106, 107,* 108,* 110, 124,* 125,* 126, 127, 135, 140, 141,* 145, 146, 158, 159,* 178
Acanthodians 153,* 154
Aceratheres, 285, 287*
Actinians, 35
Actinodesma erectum, 152*
Actinomma, 48*
Adaptation, in vertebrate limbs, 271
Admetopsis subfusiformis, 239*
Æpyornis, 266
Agaricocrinus bullatus, 166*
Agassiz, Louis, 191
Agassizocrinus dactyliformis, 166*
Age of ammonites, 8
    amphibians, 9, 121, 157–172
    coal-making plants, 121, 157–172
    cockroaches, 171
    cycads, 206
    fishes, 9, 121, 139–156
    larval life, 9, 74–86
    mammals, 8, 244–266
    man, 8
    marine floras, 9
    marine invertebrates, 9, 119–138
    medieval seed floras, 8, 9
    modern seed floras, 8
    primitive marine life, 87–100
    reason, 8
    reptiles, 8, 191
    spore-bearing floras, 9
Ages, 121
Agnostus montis, 132*
Air breathing, first, 148
Alaska, 181, 233, 300
Alaskan Range, 253
Alaskan-Siberian land-bridge, see *Siberian-Alaskan land-bridge*
Albertan faunal realm, 133
Alexandrian epoch, 140
Algæ, 35, 37,* 98, 99, 100, 131, 135, 226
  blue-green, 86, 98
  reef-making, 39, 98, 99,* 135
Algoman granites, 80, 81, 82, 84*
  Revolution, 9, 10
Alleghanian paleogeography, 162*
Allegheny Plateau, 122*
Alligators, 63
Allorisma subquadratum, 172*
Alpine phase, of Triassic, 191
  race, 311
Alps, 261
  Paleozoic, 180
Altiplanicie, 261
Amazonian Shield, 75, 235
Ambers, insects in, 264
Amblypods, 269
Ambocœlia planoconvexa, 172*
  umbonata, 152*
Ammonites, 8, 9, 16, 56, 57, 58,* 174, 184, 199, 201, 210–212, 238, 239,* 263
Amphibamus grandiceps, 187*
Amphibians, 9, 31, 47, 62–63, 157, 168, 169,* 174, 176, 185–187, 188*
  first, 139, 154–155, 156*
Ampyx nasutus, 136*
Anaptomorphus, 312
Anchisaurus, 208
Andeic geosyncline, 235
Andes Mts., 180, 233,* 235, 260
Angara, 104*
Angiosperms, 8, 25, 35, 37, 44–45, 206, 229, 236–238, 243
Anhydrite, Permian, 176
Animals, 46–65
  number of kinds of, 34

Animikian series, 87, 89, 90–91, 100
Ankylosaurs, 221
Annelids, 36, 47, 51, 55, 56,* 57, 100, 131, 133, 135
Annulata, see *Annelids*
Anodonta, 58*
Anolcites meeki, 211*
Antelopes, 275
Anthropoids, 8, 31, 307; see also *Apes*
Anticosti Island, 140
Antilles, 87, 107,* 108,* 109,* 201, 229, 231, 233,* 234,* 249, 260
Ants, 208
Ape-man, 8, 31, 322
Apennines, 261
Apes, 31, 47, 307, 309, 310, 312
Aphyllites vanuxemi, 152*
Aporrhais, 57*
  prolabiata, 239*
Appalachia, 107,* 108,* 110, 111, 126
Appalachian Mts., 179, 203,* 233,* 234*
  plateau, 122*
  Revolution, 9, 10, 177–180
Appalachic geosyncline, 88*, 106, 107*–108,* 110, 116,* 117,* 122,* 123, 124,* 125,* 126, 127, 128,* 129, 140, 141,* 142, 144, 158, 159,* 161, 162,* 168, 178
Arabia, igneous activity in, in Cretaceous, 235
Arachnida, 47, 60
Araucarias, 206
Arbacia punctulata, 55*
Archæocyathus rensselæricus, 132*
Archæopodocarpus germanicus, 184*
Archæopteryx, 224
Archæotherium, 273*
Archegosaurus, 186
Archeozoic, 9, 11, 74–86
  correlation of, 85
  length of, 15, 84
  life of, 85–86
  nature of rocks of, 83–84
Arctotheres, 275
Argoides minimus, 209*
Aridity, 144, 156, 176, 177, 182, 183, 187, 193, 202, 205, 281
Arisaig, Nova Scotia, Silurian at, 140
Aristotle, 35
Arnheim paleogeography, 128*
Arnioceras time, 200*
Art, birth of, 319, 320*
Arthrodires, 151, 153,* 154
Arthrophyta, 35, 39, 40*
Arthropoda, 36, 47, 57–61, 130, 135, 213
Asphalt pools, and fossils, 21, 266, 289, 305*
Asteroidea, 53, 54, 55*
Asteroids, 68, 69
Athyris spiriferoides, 152*
Atikokania, 80, 86, 98
  lawsoni, 99*
Atlantic border, Cenozoic of, 245–248
    Cretaceous of, 231–232
    Jurassic of, 199
    Triassic of, 193–195
Atlantic Coastal Plain, 122*
Atmosphere, changes in, 4, 301–303
  primordial, 72
Atops trilineatus, 132*
Atractites burckhardti, 211*
Atrypa nodostriata, 149*
Aulosteges, 184
Australia, glaciation in, 181, 182,* 243
Australians, 311
Australopithecus, 312
Aves, see *Birds*
Axinura canadensis, 166*
Aysheaia pedunculata, 134,* 135
Azoic era, 14*, 72–73

B

Baboons, 307
Bacteria, 18, 20, 35, 39, 91
Baculites compressus, 239*
Badlands, 255, 256*
Balanoglossus, 47, 61*
Baltic Shield, 75, 80, 104,* 261
Baluchitherium, 287,* 288
Barbados, 102, 249
Barnacles, 113
Barrell, Joseph, 69–71
Bartlett Deep, 250
Basalts, 72, 73
Basilosaurus, 265
Batholiths, 78, 113, 200,* 204, 252
Batocrinus pyriformis, 54,* 166*
Bats, 64, 270*, 271
Bears, 271, 275, 289

Beavers, 271, 273, 274, 305
Becscie paleogeography, 141*
Bees, 237
Beetles, 207
Behring portal, 103, 199, 253
Belemnites, 57, 211,* 212–213, 241
"Belted shales," 202
Beltian series, 87, 89, 91, 92, 100
Bentonite, 198
Bertie paleogeography, 141*
Bickerton, 69
Bighorn basin, 253, 254*
Billingsella coloradoensis, 132*
Biparental theory, of Earth origin, 69, 71
Birds, 8, 31, 36, 47, 64, 189, 210, 236, 308*
  Cenozoic, 266
  toothed, 224–225, 240,* 242
Bison, 304, 318
Bison latifrons, 304
  taylori, 321
Bivalves, 26, 47, 170, 172,* 211,* 238, 239,* 263; see also *Molluscs*
  fresh-water, 139, 171, 195, 202
  thick-shelled, 113, 135
Black, Davidson, 316
Black shales, Devono-Mississippian, 158
Blastids, 53, 54, 149,* 150, 152,* 166,* 167, 184
Block faulting, 161, 250, 261
  mts., 196, 197,* 257
Borderlands, 106, 107*–109,* 110–111, 112, 122; see also *Appalachia*, *Cascadia*, etc.
Boston, glaciation at, 181
Brachiopods, 26, 36, 47, 51–52, 96, 100, 113, 130, 131, 132,* 133, 136,* 137, 148, 149,* 150, 152,* 167, 170, 172,* 174, 184, 186,* 239*
Brain, dinosaur, 214, 221, 222
  gorilla, 309
  human, 308,* 309, 310*
  mammal, 64, 267, 277, 308,* 309
  primate, 307, 308,* 309
  vertebrate, 308,* 309
Branchiopods, 133, 134*
Branchiosaurus, 188*
Brancoceras ixion, 166*
  sulcatum, 152*
Brassfield paleogeography, 141*
Brazil, glaciation in, 181, 182*
Bread-fruit, in Greenland, 26
Breaks, 12, 27
Bridger basin, 253, 254*
British Columbic geosyncline, 109,* 110 192,* 193, 198, 200,* 204, 232
Brittle-stars, 53, 54
Brongniart, 24
Brontosaurus, 19,* 218, 219*
Brontotherium, 276,* 277
Brooks, T. B., 75
Brooks, W. K., 130
Brooks Range, Alaska, beginning of, 233
Bruce series, 89–90
Bryophyta, 35
Bryozoans, 26, 36, 47, 53, 113, 131, 137, 148, 167
Buckland, Rev. Dr. William, 154
Buffon, 69
Burgess shale fauna, 133–135
Burgessia bella, 134*
Burials, ceremonial, 318–319
Butterflies, 207, 237
Byssonychia radiata, 136*

C

Cacops aspidephorus, 188*
Caddis-flies, 207
Cahaba coal field, 160
Calamites, 39, 40,* 169, 170, 183
Calamostachys lanceolata, 39*
Calcium carbonate, shells of, 96, 130
Caledonian Mts., 139, 142, 146
Californic geosyncline, 109,* 110, 122,* 192,* 193, 198, 200,* 201, 204, 228, 232, 233
Calymene meeki, 136*
Cambrian, 9, 118, 123–126, 130–135
  geography of, 107,* 123–126
  life of, 130–135
Camels, 273, 274, 296, 304
Camp, C. L., 197, 198
Canadia setigera, 134*
  spinosa, 134*
Canadian Rockies, 126, 129, 133, 228
  Shield, 75–77, 79, 84, 85, 106, 107–109
Cancellaria malachitensis, 239*
Canidæ, 36
Canis, 35
  dirus, 289, 305*

Cannonball formation, 231
Capitan paleogeography, 175*
Carbon dioxide, in atmosphere, 301–302, 303
Carboniferous system, 157
Carcharodon, 246, 265
Cardioceras time, 200*
Caribbeic mediterranean, 107,* 108,* 109,* 231
  faulting in, 249
Caribou, 304
Carnivores, 36, 60, 270,* 272, 273, 274, 288–291
Carson Valley, 257
Cascade Mountains, 204,
  batholith, 252
Cascadia, 107,* 110, 111, 123, 158
Cascadian Revolution, 8, 10, 244, 258–262
Casea broilii, 188*
Castoroides ohioensis, 305
Casts, of fossils, 22,* 23
Cataract paleogeography, 141*
Catastrophisms, theory of, 12, 27
Cats, 274, 289–290
Catskill formation, 147
  Mts., Devonian delta in, 145
Cave-bear, 289, 296
Cenozoic, 8–11, 244–266
  climates of, 262
  continental deposits of, 253–257
  deposition rate in, 15
  geography of, 245–253
  length of, 15, 244
  life of, 262–266, 267–291
  subdivisions of, 245
Centipeds, 36, 47, 60
Central America, 87, 108, 234,* 249, 260
Central Cordilleran geanticline, 108,* 109,* 111, 116,* 117,* 122,* 159,* 192,* 198,* 200,* 201, 203,* 228, 229, 231, 233, 235
  history of, 232
Cephalaspis, 154, 155*
Cephalochordata, 61
Cephalopods, 36, 47, 56–57, 113, 135, 136,* 137, 138, 151,* 152,* 166,* 167, 170, 174, 184, 239,* 288; see also *Ammonites*, *Belemnites*, and *Nautilids*
Ceratocephala dufrenoyi, 149*
Ceratops, 221
Ceratopsia, 216, 221–222, 241
Ceraurus dentatus, 136*
Cereals, 8, 236
Cervalces scotti, 304
Cervus megaceros, 306*
Cestracion philippi, 168*
Chætopoda, 134*
Chalk, 226
Chamberlin, T. C., 69, 70, 71, 83
Champlain submergence, 298–299
Charlottia, 108,* 109,* 110
Chattanoogan paleogeography, 159*
Chesapeake formation, 113, 246
Chester paleogeography, 159*
Cheverie formation, 158
Chico formation, 232
Chimpanzee, 310,* 311
Chinle formation, 197–198, 202
Chonetes cornutus, 149*
  mesolobus, 172*
  setigerus, 152*
  verneuilianus, 172*
Chordata, 36, 61–65
Chronology, human, 313
Chuar series, 89, 91, 98
Cicadas, 207
Cimarron formation, 176
Cincinnati geanticline, 108,* 111, 122,* 140
Cirripeds, 59
Civilization, dawn of, 320
Clams, 36, 56, 171
Clarke, John M., 151, 154
Classification, of plants and animals, 34–36
Clays, glacial, 293, 294
  pottery, 229
Clidastes, 241*
Climacograptus typicalis, 137*
Climate, Cenozoic, 262
  changes in, 10, 114,* 173, 180–182, 205; see also *Critical periods*
  Cretaceous, 242–243
  Devonian, 155–156
  glacial, see *Glacial climates* and *Glaciation*
  Jurassic, 199, 237, 242
  Mesozoic, 242–243

Climate, Miocene, 262, 273
  Paleozoic, 180–182, 205
  Pennsylvanian, 157, 171
  Permian, 173, 181–182
  Pre-Cambrian, 97–98
  Triassic, 193, 195, 242
  Upper Cretaceous, 262
  warm, 242–243, 262
Climatius macnicoli, 153*
Clinton formation, 141,* 142, 143*
Club-mosses, 37, 40, 170
Coal, 157, 160, 161, 163–164; see also *Lignite*
  anthracite, 164, 229, 252
  Cenozoic, 250, 252
  Cretaceous, 229
  Jurassic, 202, 204
  Permian, 182
  Triassic, 194
Coal balls, 23
Coal Measures, 157, 160, 161
Coast Ranges, 122,* 203,* 204, 233, 251,* 252, 259
    batholith, 200,* 204
Cobalt mining district, 90, 94
  series, 89, 90, 97
Coccosteus decipiens, 153*
Cochliodus contortus, 168*
Cockroaches, 61, 183, 208
Coconino sandstone, 177, 178*
Coe, W. R., 30
Cœlenterata, 35, 48–51, 130
Cold-earth theory, of Earth origin, see *Planetesimal theory*
Coleman, A. P., 77, 95
Collenia ? frequens, 99*
Coloradic sea, 229, 230*
Colorado, glaciation in, 243, 262
  Plateau, 92, 257–258, 260
  ranges, 235
Colorado, Texas, human relics at, 321
Colpomya constricta, 136*
Columbia, 107,* 108,* 109,* 110
  lava plateau, 235, 251,* 259
Comanchian period, see *Lower Cretaceous*
  sea, 226, 228
Comets, 68
Composita subtilita, 172*
Condylarths, 269
Conifers, 8, 35, 37, 42–43, 45, 169,* 183, 206, 207, 236
Connecticut River range, Jurassic, 196
  Valley, 194, 195, 208, 214, 216
Continental displacement, theory of, see *Wegener theory*
Continents, elevation of, 114*
  movements of, 102–103
  origin of, 72, 73
  permanency of, 102–103
Cope, E. D., 290
Copepods, 59
Copper, 95, 204
Coralline Crag beds, 314
Corals, 9, 26, 35, 47, 48, 49, 50,* 132,* 137, 148, 149,* 150, 152,* 184
  cup, 167
  reef-, 9, 26, 113, 137, 142, 150, 166,* 181, 212,* 213, 241, 242
    and climate, 25–26, 49
Cordaites, 37, 43, 183, 205
Cordillera, 122*
Cordilleran ice-sheet, 295, 296
Cordilleric geosyncline, 88,* 106, 107*–109,* 110, 116,* 117,* 122,* 123, 124,* 125,* 126, 127, 128,* 129, 140, 141,* 144, 158, 159,* 174, 175,* 177, 198, 200,* 201, 203,* 232
Correlation, and fossils, 25
  law of, 7
Coryphodon, 269, 270*
Corythosaurus, 220*
Cosmic time, 14,* 68–71, 72
    length of, 15
Cotylosaurs, 187
Coutchiching series, 78, 80, 81, 82, 84*
Crabs, 47, 58, 213
Crania, 52
Crayfishes, 36, 58
Creodonts, 269, 288
Crepicephalus texanus, 132*
Cretaceous, 8, 226–243; see also *Lower Cretaceous* and *Upper Cretaceous*
  climate of, 242–243
  life of, 236–242
Crinids, 9, 53, 54, 113, 137, 148, 149,* 151,* 165, 166,* 167*
Critical periods, 10, 30–31, 179, 205, 241, 243, 261–262, 293
Crocodiles, 63

Cromer Forest bed, 313, 314
Cross-fertilization, of plants, by insects, 45, 206, 236, 237
Crust, original, 71, 72, 82–83
Crustacea, 58–60, 96, 130, 133, 134;* see also *Trilobites*, etc.
Cryphæus punctatus, 152*
Cryptolithus tesselatus, 136*
Cryptorhytis utahensis, 239*
Cryptozoön, 135
Ctenacodon, 269*
Ctenodonta cingulata, 136*
Cuba, 201
Cuttle-fishes, 57
Cuvier, 12, 24, 35, 51
Cyanophyceæ, 86, 98
Cyathocrinus multibrachiatus, 166*
Cyathospongia reticulata, 136*
Cycads, 8, 23,* 35, 37, 43–44, 45, 197, 206–207, 236, 262
Cyclonema humerosum, 136*
Cynodictis, 289
Cynodonts, 268
Cypresses, 43, 206
Cyrtodonta huronensis, 136*
Crytolites ornatus, 136*
Cystids, 53, 54
Cystiphyllum vesiculosum, 152*

D

Dalmanella testudinaria, 136*
Daonella dubia, 211*
Daphænus, 289
Dark ages, of Earth history, 72–73
Darwin, Charles, 27, 29, 237
"Dawn man," 317, 322; see also *Man, Piltdown*
Dawson, Sir William, 85, 99, 185
Dawsonites time, 192,* 198
De Geer, 294
Deer, 274
Deiphon forbesi, 149*
Deltas, Devonian, 117,* 144, 147
  Dunkard, 176
Dendrerpeton acadianum, 186
Deposition, rate of, 15
Deposits, abyssal, 102
  continental, 146–147, 193–195, 197–198, 202, 228–229, 253–257
Deserts, 192,* 193, 202, 209, 257
Devonaster eucharis, 55*
Devonian, 9, 11, 115–118, 123, 144–147, 149–156
  climate of, 155–156
  flood cycle in, 115–118
  fresh-water deposits of, 146–147
  geography of, 108,* 116,* 117,* 144–147
  life of, 150–156
Diaphorostoma niagarense, 149*
Diasparactus zenos, 188*
Diastrophism, 160, 232, 244, 252, 292, 300, 301; see also *Mountain making*
Diatoms, 35, 38,* 252
Diatryma, 266
Diceratheres, 285, 286*
Diceratherium cooki, 286*
Dicotyledons, 37
Dictyonema crassibasale, 51*
Dielasma bovidens, 172*
Dinichthys, 154
Dinictis, 290, 291*
Dinocyon, 289
Dinornis, 266
Dinosaur National Monument, Utah, 216
Dinosaurs, 8, 47, 64, 187, 189, 202, 214–222
  armored, 215
  Cretaceous, 241–242
  duck-billed, 20, 215, 241
  eggs of, 20, 215, 222,* 223
  extinction of, 216, 242
  Jurassic, 242
  Triassic, 195
Dioon edule, 44*
Dipleura dekayi, 152*
Diplodocus carnegiei, 218
Diplograptus pristis, 51*
Dipnoans, 154
Dipterus valenciennesi, 153*
Disturbances, 11, 102
  Acadian, 9, 139, 144
  Taconian, 9, 129
Dœdicurus, 275*
Dogs, 29, 36, 271, 273, 274, 288–289
Dolichorhinus hyognathus, 276*
Dolichosoma, 169*

Dolomites, 135, 142
Domatoceras militarium, 171*
Dorypyge curticei, 132*
Dragon-flies, 61, 207
Dragons, flying, 208, 223
Drainage, Pleistocene, 298–299
Drift, 293
Dubois, E., 315
Dunbaria, 184, 185*
Dunkard series, 176
Dust, volcanic, in atmosphere, 302–303
Dutton, C. E., 202

E

Eagle Pass formation, 231
Ears, origin of, 63
Earth, age of, 12–15
  before geologic time, 66–73
  dark ages of, 72–73
  interior of, 73
  origin of, 68–71
  shrinkage of, 4
Earthquakes, 161, 252, 257
Earthworms, 36
Echinarachnius, 18*
Echinids, 53, 54, 55,* 113, 166,* 184, 213
Echinoderms, 36, 53–54, 130, 150, 167; see also *Blastids*, *Crinids*, etc.
Economic products, Ordovician, 129–130
    Proterozoic, 91, 94–95
    Silurian, 142, 144
  see also *Coal*, *Salt*, etc.
Eden paleogeography, 128*
Edentates, 269, 270*
Edgewood paleogeography, 141*
Edmonton formation, 231
Eggs, dinosaur, 20, 215, 222,* 223
  reptilian, 63, 187
Egypt, early elephants in, 282, 283
Elasmosaurus, 240,* 241
Elephants, 25, 271, 282–285, 296, 303–304; see also *Mammoths* and *Mastodons*
Elephas, 283*
  columbi, 303, 304*
  imperator, 303, 304*
  primigenius, 303, 304*, 306*
Emergences, 114,* 127, 160
Endoceras, 138
Endothyra baileyi, 166*
Entelodonts, 273, 274
Environment, and evolution, 30–33, 187–188, 205, 280–281
  changes in, 5, 10, 30–33, 179, 277, 280–281; see also *Critical periods*
  recorded by fossils, 25–26
Eoanthropus, 311, 313, 317–318, 322
Eocene, 8, 245, 246, 248, 250, 252, 253, 254, 259, 261
  climate of, 262
  fishes, 17*
  life of, 263,* 265, 266, 269, 270,* 272–273, 280, 281, 285, 288, 289, 312
Eodiscus speciosus, 132*
Eogenic, 8
Eohippus, 279,* 280
Eoliths, 313–314, 318
Eospermatopteris, 156*
Eotitanops, 275, 276*
Eotomaria supracingulata, 136*
Eozoön canadense, 85, 98–99
Ep-Archeozoic interval, 80, 82
Epihippus, 280
Epi-Proterozoic interval, 89, 96
Epochs, 11, 245
Equisetum, 197
Eras, 10–11
Eria, 260,* 261, 262
Erosion, cycle of, 10
  intervals, 10, 12, 80, 82, 89, 96, 100
  rate of, 13
Erratics, 293
Eruptions, fissure, 236, 259
Eryma, 213*
Eryon, 213*
Eryops, 185
Equus, 279,* 280
  scotti, 280
Eucalyptocrinus crassus, 149*
Eumicrerpeton, 185
Euphemus carbonarius, 172*
Eurypterids, 47, 148, 150*
Eurypterus remipes, 150*
Eusarcus scorpionis, 150*
Eustachian tube, origin of, 63
Evergreens, primitive, 155
Evolution, 27–33
  accelerated, 31, 33

Evolution and environment, 30–33, 187–188, 205, 280–281
  and fossils, 24
  and Paleontology, 31–33
  retrogressive, 30
Exogyra costata, 239*

F

Farming, beginning of, 320
Fault scarps, recent, 257
Faulting, 161, 193, 248, 249, 252, 260
Favosites occidentalis, 149*
  polymorpha, 50*
Feather-stars, 36, 53, 54
Felis, 35, 290, 291*
Ferns, 35, 37,* 40–41, 205, 207, 236, 262
Fernvale paleogeography, 128*
Finger Lakes, N. Y., 298
Fishes, 5, 9, 31, 36, 47, 61–62, 139, 151, 153,* 176, 255, 308*; see also *Lung-fishes*
  armored, 151, 153,* 154, 288
  Eocene, 17*
  fresh-water, 148, 151, 153,* 195
  number of kinds of, 34
  Old Red, 147, 151, 153,* 154
  oldest known, 137, 147
Flatworms, 36, 51
Flies, 207
Flood cycles, 11, 114–118
Floods, oceanic, recurrent, 102, 103–105, 114–118
Floras, first, 155
  modern, 236–238
  Pennsylvanian, 157, 168–170, 176
  Triassic-Jurassic, 205–207
Florida, first appearance of, 249
Folding, 235, 248, 260, 261
Folsom, New Mexico, human relics at, 321
Foot, human, 309
Foraminifera, 46–47, 113, 226, 263
Forbesiocrinus wortheni, 166*
Forests, first known, 9, 150, 155, 156*
Formations, 11–12, 121
Fort Union formation, 242
Fossil Cycad National Monument, 206
Fossils, 16–26
Fossils, definition of, 16–17
  kinds of, 21–24
  preservation of, 17–21
  teachings of, 24–26, 113
Foundering, around Indian Ocean, 235
  of borderlands, 110–111
  of continents, 87
  of Holarctica, 261
Fox Hills formation, 231
Fracastoro, 24
Frankfort paleogeography, 128*
Franklinic geosyncline, 107,* 108,* 110, 124*
Front Ranges, 122*
Fruits, 8, 236
Füchsel, 6
Fungi, 18, 20, 35, 37
Fusulinids, 170, 172,* 184

G

Galaxy, 66
Galileo, 66
Galley-worms, 60
Gamachian paleogeography, 128*
Gangamopteris, 183, 205
Ganoids, 47, 153,* 154
Gaspé, 117,* 140, 142, 145, 147 151, 154,
Gastropods, 22,* 28,* 47, 55–56, 57,* 96, 100, 130, 131, 132,* 133, 135, 136,* 149,* 172,* 239*; see also *Snails*
  fresh-water, 176
Gastrulæ, 47, 50
Geanticlines, 106, 107*–109,* 111, 112, 122; see also *Central Cordilleran*, *Cincinnati*, and *New Brunswick*
Gemündina stürtzi, 154*
Genesee paleogeography, 117*
Genus, 35
Geologic time, beginning of, 72
  time-table, 6–12
Geosynclines, 106–111, 113, 115, 122; see also *Appalachic*, *Cordilleric*, etc.
Gibbons, 307, 310, 311,* 312
Gigantosaurus, 218
Gilboa Devonian forest, 155, 156*
Gill-clefts, 62
Gingko, 183
Girardeau paleogeography, 141*

Glacial climates, causes of, 300–303
  epochs, number of, 297
  Period, see *Pleistocene*
Glaciation, 8, 9
  Cretaceous, 243
  effects of, 298–299
  Permian, 173, 180, 181–182, 205
  Pleistocene, 292–303
  Proterozoic, 97–98
Glauconite, 232
Glossopteris, 183
  indica, 183*
Glyphioceras incisum, 171*
Glyptodonts, 274, 275*
Gold, 82, 94, 201, 204
Gomphotherium, 283,* 284
Goniatids, 166*
Goniophora carinata, 152*
Gorilla, 309, 311
Gowganda conglomerate, 90, 98
Graben, 194
Grammysia bisulcata, 152*
Granatocrinus leda, 152*
Grand Canyon, 113–114, 158, 177, 178,* 183, 257–258
    Proterozoic of, 91–92, 93*
    Revolution, 9, 10, 89, 92, 178*
    series, 98
Granite, intrusions of, 80, 81, 89, 146, 179, 257
  of continents, 72
  of original crust, 71
Graphite, 79, 100
Graptolites, 35, 49, 51,* 135, 137,* 148
Grasses, 8, 236, 273, 274
Grasshoppers, 207
Grazing, 274, 277, 278, 279, 280
Great Basin, 122,* 129, 196–198, 208, 235, 251,* 257
Great Lakes, ancestral, 298
Great Plains, 122*
Great Salt Lake, 297–298
Great Valley of California, 122,* 204, 247,* 250, 251,* 253
Green River lake, 164, 253, 255
Greenland ice-sheet, 296
  warm climate in, 26, 236, 243
Gregory, H. E., 198
Grenville series, 75, 78–79, 80, 81, 85, 90, 100
Ground sloths, 274, 275,* 305
Gryphæa mucronata, 238*
Gulf border, Cenozoic of, 248–249
Gulf of Lower California, 250
Gulf of Mexico, origin of, 229–231
Gumbotil, 296
Gymnosperms, 37, 45, 205–207
Gymnotoceras russelli, 211*
Gypsum, 144, 163, 175,* 177, 197, 200*
Gyroceras, 151*

H

Habitats, 25
Hall, James, 151
Halysites catenulatus, 149*
Hamilton time, 12, 115, 116*
Heart-urchins, 238
Hebertella sinuata, 136*
Helicotoma planulatoides, 136*
Heliophyllum halli, 50,* 152*
Helminthoidichnites meeki, 100*
Hematite, Silurian, 142
Hemichordata, 61
Herbs, 236
Heredity, 29–30
Hermit shale, 177
Herodotus, 13
Hesperornis regalis, 224, 225,* 240*
Heteroceras stevensoni, 239*
Hexacoralla, 212,* 213
Himalayas, 261
Hippopotamus, 296
Histometabasis, 23
Historical Geology, principles of, 6–7
    scope of, 3–5
Holarctica, 103, 104,* 156, 170, 215,* 260,* 267, 268*
Holmia bröggeri, 132*
Holoptychius flemingi, 153*
Homalonotus, 151*
Homo primigenius, 311, 313, 318–319
  sapiens, 311, 313, 319–320, 322
Honduras, Mesozoic mts. of, 249
Hoplophoneus, 290, 291*
Hormotoma gracilis, 136*
Hornea, 148
Horses, 271, 272, 273, 274, 277, 278–281, 296, 304, 318, 319
Horseshoe crabs, 47
Horsetails, 35, 39, 207

Horton formation, 158
Hot-earth theory, of Earth origin, see *Planetoidal theory*
Hudson Bay, first appearance of, 299
Huenella texana, 132*
Humboldt Mts., 204
Huronian, 75, 87, 89–92
Hustedia mormoni, 172*
Hutton, James, 6, 13
Huxley, T. H., 185
Hyænodon, 269*
Hyattidina congesta, 149*
Hydroids, 35, 48
Hydrosphere, increase in, 102
  origin of, 72–73
Hylopus logani, 185
Hymenocaris ?, 134*
Hyolithes primordialis, 132*
Hyrachyus, 285
Hyracotherium, 279*

I

Ice age, Permian, 173, 180, 181–182
  Pleistocene, 292–306
  Proterozoic, 97–98
Ice ages, causes of, 300–303
Ice-sheets, thickness of, 296
Ichthyornis, 224–225, 240*
Ichthyosaurs, 209, 210,* 240*
Ichthyosaurus, 210,* 240*
Igneous activity, 195, 259, 261; see also *Volcanoes*
Illinoian glacial stage, 313
Imprints, fossil, 24
India, glaciation in, 181, 182*
  igneous activity in, 236
Inoceramus vanuxemi, 239*
Insectivores, 268, 269, 270,* 311
Insects, 8, 9, 20, 36, 47, 60–61, 157, 171, 174, 176, 185,* 206, 207
  and plants, 45, 206, 236, 237
  Cenozoic, 264
  Jurassic, 242
  number of kinds of, 34
  Pennsylvanian, 171
  Permian, 183–184
Interglacial warm times, 182, 296–297, 302, 303
Interior Plateaus, British Columbia, 235
Intermontane basins, 161, 194, 253, 254*
Intervals, of erosion, 10, 12, 80, 82, 89, 96, 100
Intrusion, principle of, 7
Intrusions, granitic, 80, 81, 89, 146, 179, 257
  granodiorite, 204
Invertebrates, 31, 35; see also *Brachiopods*, *Cephalopods*, etc.
  defined, 46
  number of kinds of, 34
Iowan glacial stage, 313
Irish deer, 306*
Iron, 91, 98, 100, 142, 194
Isostasy, 73
Isotelus iowensis, 136*
Ivory, in tundras, 300

J

Jeans, Sir James, 66, 69, 71
Jellyfishes, 18, 24, 35, 47, 48, 133
Joannites nevadanus, 211*
Joggins section, Nova Scotia, 161, 171, 185, 186
John Day basin, 20, 255
Jurassic, 8, 199–213
  climate of, 199, 237, 242
  continental deposits of, 202
  geography of, 199–204
  life of, 205–213

K

Kaibab limestone, 177, 178*
  Plateau, 258
Kangaroo, 65, 267
Kansan glacial stage, 313
Kant, Immanuel, 68, 69
Karroo system, 189
Keewatin ice-sheet, 295, 296, 298
  series, 77–78, 80, 81, 82, 84
Keith, Sir Arthur, 317
Kelvin, Lord, 14
Keokuk paleogeography, 159*
Keraterpeton, 169*
Keweenawan series, 75, 89, 94–95
Killarney Mts., 125,* 126
  Revolution, 9, 10, 89, 95–96
Kinderhook paleogeography, 159*
Kirkland Lake gold district, 82

Klamath Mts., 204
Knowlton, F. H., 24, 45
Kootenai formation, 227,* 228–229
Kritosaurus, 220*

L

Labradorean ice-sheet, 295, 296
Lake Bonneville, 297–298
  Champlain, 299
  Chicago, 298
  Florissant, 20, 264
  Saginaw, 298
  Whittlesey, 298
Lake Superior copper region, 95
Lakes, glacial, 294
Lambdotherium popoagicum, 276*
Lamellibranchs, 56, 58,* 136,* 152*
Lance formation, 231, 235
Lancelets, 5, 47, 61
Land-bridges, 103, 181, 301
  Greenland-Norway, 103, 246, 284; see also *Eria*
  Mediterranean, 285
  Panama, 103
  Siberian-Alaskan, 103, 199, 253, 268,* 274, 280, 284
Lane, A. C., 13
Laplace, 68–69
Laramide Mts., 253, 259
  Revolution, 8, 10, 216, 231, 233–236, 241, 242, 244
Latirus, 57*
Latomœandra seriata, 212*
Laurentia, 104*
Laurentian-Algoman granites, 94
    Revolution, 9, 10, 81
  Mts., 81
  peneplain, 82
  series, 75, 77, 78, 80, 81, 82, 84*
Lava fields, and paleogeography, 112–113
  flows, 204, 236, 259
Lawson, A. C., 77, 257, 258
Leaching in tills, degrees of, 296
Leda bellistriata, 172*
Leg, human, 309
Lehmann, 6
Leidy, Joseph, 290
Lemurs, 31, 47, 272, 307, 310, 311, 312
Leonard paleogeography, 175*
Lepidodendron, 40, 43,* 183
Lepidophyta, 35, 39–40, 43*
Leptæna rhomboidalis, 136*
Liberty paleogeography, 128*
Life, abundance of, 16, 28
  procession of, 31
  wastage of, 28
Lignite, 229, 231, 248, 250, 252
Limacodites mesozoicus, 207*
Limestones, 16, 97, 127, 142, 158, 167, 181
  crinidal, 54, 165, 167*
  fusulinid, 170
  pentremital, 167
Limnoscelis paludis, 188*
Lingula, 52
Lingulepis acuminata, 132*
Linnæus, 34, 307
Linton, Ohio, amphibians, 186
Lion, 296
Lipalian interval, 89, 96, 100, 130
Lithostrotion proliferum, 50*
Lizards, 63, 208
Llamas, 274, 304
Llanoria, 107,* 108,* 110, 116,* 160, 163, 176, 177
Lobsters, 36, 47, 58, 213
Lockport time, 141,* 143*
Locusts, 207
Loess, 294
Logan, Sir William, 74–75, 164, 185
"Lost intervals," 12
Lower Cretaceous, 8, 226–229, 236–242
    geography of, 226–229
    life of, 236–242
Lowville time, 127
Loxomma, 169*
Lung-fishes, 30, 47, 153,* 154, 197
Lycopods, 155
Lyell, Sir Charles, 102, 185
Lyginodendron oldhamium, 42*

M

Macacus, 316
Machærodus, 290, 291*
Macrotæniopteris magnifolia, 207*
Madison limestone, 158, 159*
Magnolias, 236, 243, 262
Maidenhair trees (gingkos), 37, 43, 183, 206

Maine, volcanoes in, 142
Mammals, 8, 31, 36, 47, 64–65, 189, 210, 236, 265, 267–292, 308*
  archaic, 8, 202, 268–269, 270*
  brain in, 64
  Cretaceous, 242
  limb adaptations in, 271
  Mesozoic, 267–268
  modern, 269–271
  primitive, 191
Mammoths, 285, 303, 304,* 318, 320*
  Columbian, 296, 303, 304,* 321
  frozen, 16, 20, 300, 303
  imperial, 296, 303, 304*
  woolly, 296, 303, 304,* 306*
Mammut americanum, 284, 304*
Man, 8, 47, 236, 262, 307–323
  Aurignacian, 313, 319, 322
  Azilian, 313, 320
  chronology of, 313
  Crô-Magnon, 313, 319–320
  Heidelberg, 311, 313, 317–318, 322
  Java, 311, 313, 315
  Magdalenian, 313, 319
  Mousterian, 313, 318
  Neandertal, 311, 313, 318–319, 322
  Peking, 311, 313, 315–317, 322
  Piltdown, 311, 313, 317, 322
  Pleistocene, in North America, 321–322
  Rhodesian, 313
  Solutrean, 313, 319
Manteoceras manteoceras, 276*
Manticoceras oxy, 152*
Marble, Ordovician, 130
Marine record, and chronology, 105
Marrella splendens, 134*
Marsh, O. C., 290
Marsupials, 47, 65, 267, 268, 269, 270,* 272
Mastodon, 283,* 304*
Mastodons, 274, 284–285, 303–304, 321
Matthew, W. D., 281, 291, 318
Mauch Chunk formation, 168
Mazon Creek, Illinois, 186–187
Meekoceras, 196
  gracilitatis, 211*
Meekoceras sea, 192,* 196
Megalictis, 289
Megalonyx, 305
Megatherium, 305
Melocrinus paucidactylus, 167*
Melonechinus, 167
  multiporus, 166*
Menipes, 53*
Merostomata, 134*
Merychippus, 280
Mesabi district, Minn., 91, 92*
Mesatirhinus petersoni, 276*
Mesohippus, 279*
Mesolithic culture, 313, 320
Mesosaurus, 189
Mesozoic, 8, 11, 190–191
  climate of, 242–243
  deposition rate in, 15
  distribution of, 190
  divisions of, 190–191
  Early, 8, 191–213
  Late, 8, 226–243
  length of, 15, 190
  mammals of, 267–268
  paleogeography of, 109*
Metamorphosis, in insects, 207
Metazoa, 48
Metopolichas breviceps, 149*
Mexican geosyncline, 108,* 109,* 110, 116,* 117, 159,* 162,* 174, 175,* 192,* 198, 200,* 201, 226
Miacidæ, 288
Micraster, 238*
Migrations, of plants and animals, 103, 198, 215,* 268,* 273, 275, 282, 283–284
Milky Way, 66
Miller, Hugh, 147, 154
Miocene, 8, 246, 249, 252, 255, 256,* 259, 260, 261, 280, 281, 285, 289, 309, 312
  climate of, 262, 273
  echinids of, 18*
  mammals of, 273–274
Mississippi embayment, 248
  River, 203, 234
  Valley, 122,* 126, 127, 158, 161
    elevation of, 249, 260
Mississippian, 9, 118, 123, 157, 158–160, 165–168
  geography of, 158–160
  life of, 165–168
Missouri River, 298

Moas, 266
Moenkopi formation, 197
Mœritherium, 282, 283*
Moir, J. Reid, 314
Molaria spinifera, 134*
Molds, of fossils, 22,* 23
Mollisonia gracilis, 134*
Molluscoidea, 36, 51–53, 130
Molluscs, 9, 36, 47, 55–57, 130, 131, 137, 149, 184, 201, 238, 239,* 263; see also *Gastropods*, etc.
  number of kinds of, 34
Mongolian race, 311
Monkeys, 31, 47, 271, 307, 310, 311,* 312
Mono Lake, 257
Monocotyledons, 37
Monomorella noveboracum, 149*
Monotremes, 64
Monteregian Hills, 146
Monterey formation, 252
Moodie, R. L., 187
Morrison time, 200,* 202
Morrow paleogeography, 162*
Mosasaurs, 241
Mosses, 35, 37
Moulton, F. R., 69, 71
Mound-builders, 321
Mt. Royal, 145,* 146
Mountain making, 114, 300, 301
  Cenozoic, 250, 258–262
  Cretaceous, 233–236
  Devonian, 144
  Jurassic, 190–191
  Mississippian, 160
  Ordovician, 129
  Pennsylvanian, 157, 160, 161, 163
  Permian, 173, 175,* 177–180
  Pre-Cambrian, 80, 81, 89, 95–96
  Silurian, 142
  Triassic, 195–196
Mud-puppies, 62, 188*
Muller, H. J., 30
Multituberculates, 268, 270*
"Mummy," dinosaur, 20
Musk-ox, 296, 304
Mustelidæ, 289
Mutations, 29–30
Myalina subquadrata, 172*
Mylodon, 305
Myriapods, 60, 148

N

Naraoia compacta, 134*
Nautilids, 56, 57, 136,* 138, 167
Nebraskan glacial stage, 313
Nebulæ, 66, 67*
Nebular theory, of Earth origin, 68–69
Necturus maculatus, 188*
Negative areas, 106–110
Nemathelminthes, 36, 51
Neogenic, 8
Neolithic culture, 313, 320
Nereis, 56*
Nevadian Revolution, 8, 10, 190–191, 204, 228, 257
New Brunswick geanticline, 107,* 108,* 111, 126
  volcanoes in, 142
"New Red" sandstone, 147
New Scotland paleogeography, 116*
New Stone Age, 313, 320
Newark series, 194, 195
Newfoundland ice-sheet, 296
Niagara Falls, 142, 143,* 298
Niagaran epoch, 140
Nickel, Canadian, 94
Nicola formation, 198
Nile, delta of, 13
Nimravus, 290, 291*
Nonconformities, 12
Nordic race, 311
North America, major geologic features of, 105–111, 122
  paleogeography of, 107*–109,* 114, 115–118; see also *Cambrian*, etc.
Nova Scotia ice-sheet, 296
  Pennsylvanian of, 161
Novascotica, 107,* 108,* 110, 111, 126
Nummulites, 263

O

Oceanic basins, increase in, 4, 73
  origin of, 72, 73
  permanency of, 102–103
Oceans, recurrent spread of, over lands, 4, 102, 103–105, 114, 115–118; see also *Paleogeography*
Ocoee Mts., 123, 125,* 126
Odontocephalus selenurus, 152*
Ohio River, 298

Oil shales, 177, 255
Old Red sandstone, 146–147, 154
Old Stone Age, men of, 313, 314–320
Oldhamina, 184
Olenellus thompsoni, 132*
Oligocene, 8, 246, 248, 249, 250, 252, 253, 256,* 259, 261, 266, 280, 281, 285, 289, 309, 312
  climate of, 262
  mammals of, 273
Oneonta formation, 147
Onondaga paleogeography, 116*
Ontaric geosyncline, 88*
Ontario, 82, 94–95
Onychocrinus ramulosus, 166*
Onychophora, 134,* 135
Ophiacodon mirus, 188*
Ophiurids, 53, 54
Ordovician, 9, 118, 123, 127–129, 135–138
  geography of, 107,* 127–129
  life of, 135–138
Oreodonts, 21,* 273, 274
Ores, Proterozoic, 87
Oriskany paleogeography, 116*
Ornithischia, 216, 219–223
Ornithomimes, 218
Ornithopoda, 219–220
Orohippus, 280
Orthis tricenaria, 136*
Orthoceras multicameratum, 136*
Orthonota undulata, 152*
Osborn, H. F., 277, 291
Osteolepis macrolepidotus, 153*
Ostracoderms, 153,* 154, 155*
Ostracods, 59
Ostrea larva, 239*
  lugubris, 239*
Ottoia prolifica, 134*
Ouachitic mountains, 163
Ouachitic-Sonoric geosyncline, 107,* 108,* 110, 124,* 126, 127, 128,* 159,* 162,* 163, 178, 179
Overthrusting, 129
Owen, Sir Richard, 185
Owenella antiquata, 132*
Owens Valley, 257
Oxygen, beginning of, in atmosphere, 91
Oysters, 25, 113, 201, 238, 239*
Ozark dome, 122*
Ozarkia, 106, 108*

P

Pachydiscus seppenradensis, 212
Pacific border, Cenozoic of, 250–253
    Cretaceous of, 232–233
    Jurassic of, 199–201
  geosyncline, 106, 108,* 109,* 110, 116,* 117,* 159,* 162,* 175,* 192,* 198–199, 200,* 213, 232–233, 247; see also *British Columbic* and *Californic geosynclines*
  mts., 203,* 204, 234,* 251,* 260; see also *Cascade*, *Coast Range*, and *Sierra Nevada Mts.*
Painted Desert beds, 202
Palæanthropus heidelbergensis, 311, 313, 317–318
Palæomastodon, 283,* 284
Palæophonus hunteri, 150*
  nuncius, 150*
Palæosauropus, 168
Palæosyops leidyi, 276*
Paleocene, 312
Paleogeographic maps, making of, 111–118
Paleogeography, 101–118
  and fossils, 25
  Cambrian, 107,* 123–126
  Cenozoic, 245–253
  Devonian, 108,* 116,* 117,* 144–147
  Jurassic, 199–204
  Lower Cretaceous, 226–229
  Mississippian, 158–160
  of North America, 114, 115–118; see also *Cambrian*, etc.
  Ordovician, 127–129
  Pennsylvanian, 160–163
  Permian, 174–177
  principles of, 101–102
  Proterozoic, 87, 88
  Silurian, 139–143
  Triassic, 191–199
  Upper Cretaceous, 229–233
Paleoliths, 314
Paleontology, and evolution, 31–33
Paleophysiography, Cambrian, 125*
  Jurassic, 203*
Paleozoic, 9, 11, 119–123
  Alps of Europe, 180
  climate of, 180–182, 205

Paleozoic, deposition rate in, 15
  divisions of, 121–123
  Early, 9, 123–138
  Late, 9, 157–189
  length of, 15, 119
  Middle, 9, 139–156
  North American, distribution of, 120–121
  thickness of stratified rocks in, 14
Palisade Disturbance, 8, 195–196
  range, Jurassic, 196
Palisades, New Jersey, 195
Palms, 37, 43, 262, 264
Paludestrina, 28*
Pampas formation, 266
Panama portal, 247,* 249
Pangea, 4
Pantotheria, 268
Paradoxides harlani, 132*
Parahippus, 280
Paterina bella, 132*
Pearly nautilus, 57
Pearya, 107,* 108,* 110
Peat, 160
  bogs, fossils in, 20
Peccaries, 273, 274, 296, 304
Pecopteris dentata, 41*
Pennsylvania, Devonian delta in, 144
Pennsylvanian, 9, 118, 123, 157, 160–163, 168–172
  climate of, 157, 171
  geography of, 160–163
  life of, 168–172, 185–187
Penokee district, Minn., 90
  Mts., 89, 96
Pentamerus oblongus, 149*
Pentremites, 167
  conoideus, 166*
  elongatus, 166*
Pentremitidea filosa, 152*
Periods, 11
  length of, 118
  typical, 115–118
Peripatus, 135
Permian, 9, 121, 123, 157, 173–189
  climate of, 173, 181–182
  geography of, 174–177
  life of, 182–189
Petrifaction, 22
Petrified Forest National Monument, Ariz., 207
Petrified forests, 198
Petroleum, 164–165, 177, 248, 252, 255
  as preservative of fossils, 21
Phacops bufo, 152*
Phillipsia major, 172*
Phiomia, 284
Phlaocyon, 289
Phororhacos, 266
Phosphates, 177, 246
Phosphoria formation, 177
Phyla, 35
Phyllocarids, 133, 134*
Phytosaurs, 197, 208
Pinal schists, 80
Pines, 43, 206
Pisces, see *Fishes*
Pithecanthropus, 311, 313, 315, 322
Placentalia, 65
Planetesimal theory, of Earth origin, 69, 70, 71
Planetesimals, 69, 70, 71, 83
Planetoidal theory, of Earth origin, 69–71
Planetoids, 70
Planets, 68, 69, 71
Planolites corrugatus, 100*
Plants, 34–45
  and insects, 45, 206, 237
  Cenozoic, 263,* 264
  coal, 168–170, 176
  Devonian, 155–156
  flowering, see *Angiosperms*
  land, 138, 139, 168
  number of kinds of, 34
  origin of, 36
  Permian, 182–183
  reproduction in, 38
  Silurian, 147–148
  Triassic, 194, 195
Platinum, in Canada, 94
Platyceras angulatum, 149*
Platycrinus symmetricus, 166*
Platyhelminthes, 36, 51
Platystrophia laticosta, 136*
Plectoceras (?) occidentale, 136*
Pleistocene, 8, 252, 253, 259, 260, 261, 266, 280, 289, 292–306, 309
  deposits of, 293–294
  drift, 157

Pleistocene, length of, 292
  life of, 303–306
  mammals of, 275
Plesiosaurs, 209, 240*
Pliocene, 8, 248, 249, 252, 253, 255, 257, 258, 259, 260, 261, 266, 274, 280, 284, 285, 312
  mammals of, 275
Pliopithecus, 311
Pocono series, 168
Podokesaurus, 217*
Pontiac schists, 79*
Popo Agie formation, 196
Porcupine gold district, 82
Porifera, 35, 47, 48, 49*
Porospora gigantea, 46
Portage paleogeography, 117*
Portals, oceanic, 103, 199, 247,* 249, 253
Positive areas, 106, 112; see also *Shields*
Posture, in man, 307, 309
Potomac series, 227,* 228, 229
Pottsville paleogeography, 162*
Pre-Cambrian time, 74–100
Primates, 236, 242, 307–312
Priority, law of, 34
Proangiosperms, 206
Proboscideans, 275, 282–285; see also *Mammoths* and *Mastodons*
Productella hirsuta, 152*
Productids, 184
Productus, 167
  cora, 172*
  nebraskensis, 172*
  punctatus, 172*
  semireticulatus, 172*
Promerycochœrus carrikeri, 21*
Propliopithecus, 311
Proterozoic, 9, 11, 87–100
  climate of, 97–98
  Early, 89–90
  Late, 89, 92–95
  length of, 15, 87
  life of, 98–100
  Middle, 89, 90–92
  mineral wealth of, 94–95
  ore making in, 87
  paleogeography of, 87, 88
Protoceras, 290*
Protoceratops, 222*
Protochordates, 47
Protohippus, 279*
Protophyta, 35
Protorohippus, 279*
Protowarthia cancellata, 136*
Protozoa, 35, 36, 46–47, 166,* 172*
Psaronius, 155
Pseudælurus, 290
Pseudomonotis hawni, 172*
  subcircularis, 211*
Pseudomonotis time, 192*
Pseudomorphs, of fossils, 23
Psychozoic era, 8, 11
Pteranodon, 223, 242
Pteraspis rostrata, 153*
Pterichthys, 154
  milleri, 153*
Pteridophyta, 35, 40–41
Pteridospermophyta, 35, 37, 41–42
Pterinea demissa, 136*
  flabellum, 152*
Pterodactyls, 8, 47, 64, 223, 240,* 242
Pterygotus buffaloensis, 148
Ptychoparia kingi, 132*
Puget Sound area, 250, 251,* 252, 262
Pyrenees, 261
Pyropsis bairdi, 239*

Q

Quaternary, 244

R

Raccoons, 271, 274, 289
Radiolaria, 46, 47, 96, 98, 100
Radium, and age of Earth, 14
  effect of, on mutations, 30
Rafinesquina alternata, 136*
Rain prints, "fossil," 24
Rains, first, 72
Rana temporaria, 63*
Rancho La Brea, 21, 289, 305*
Recent time, 244, 294
Re-creations, theory of, 12, 27
Red beds, 20, 91, 94, 144, 145, 156, 163, 168, 176, 177, 194, 197, 200*
Redwall limestone, 158, 177, 178*
Redwoods, 43
Reefs, algal, 39, 98, 99,* 135
  bryozoan, 53

Reefs, coral, 113, 137, 142, 144, 150, 156, 181, 212,* 213
    and climate, 49
  sponge, 213
Reindeer, 296, 318, 319, 320
Religious instinct, dawn of, 318–319, 322
Reptiles, 9, 31, 47, 63–64, 174, 176, 187–189, 197, 240, 241, 308*
  Cretaceous, 240,* 241; see also *Dinosaurs*
  flying, 223
  marine, 209–210
  Mesozoic, 191
  Pennsylvanian-Permian, 187–189, 288
  Triassic-Jurassic, 208–210; see also *Dinosaurs*
Revolutions, 10, 85, 102; see also *Appalachian Revolution*, etc.
Rhamphorhynchus phyllurus, 223*
Rhinoceroses, 272, 273, 274, 280, 285–288
  frozen, 20, 300
  woolly, 288
Rhynchotrema capax, 136*
Rhynchotreta americana, 149*
Rhynia, 37, 148
Rhythm, in oceanic floods, 105
Richmondian sea, 128,* 129
Richthofenia, 186*
Ridgway tillites, 262
Rif Mts., 261
Rochester shale, 143*
Rocky Mt. geosyncline, see *Cordilleric geosyncline*
  Mts., 122,* 234,* 235, 259, 260
Rodents, 270,* 272, 273, 274, 305
Rohwer, S. A., 61
Rotalia, 48*
Roundworms, 36, 51
Ruminants, 272, 273, 274
Rushes, 35, 39, 40,* 155, 169,* 207, 236
Rutiodon, 208*

S

Sabre-tooth tigers, 274, 290, 291,* 296, 304
Sageceras gabbi, 211*
Sago "palms," 43
St. Lawrencic geosyncline, 106, 107*–108,* 123, 124,* 127, 129, 135, 144
St. Louis paleogeography, 159*
Salamanders, 62, 188*
Salina formation, 144
Salinity, of rivers, variation in, 13
Salt, 144, 163, 175,* 176, 177, 298
  domes, 249
San Andreas rift, 252, 259
San Angel, Mexico, man, 321
San Francisco earthquake, 252
San Juan basin, 253
San Luis Obispo Mts., 177, 193
Sand-dollars, 18,* 54
Sands, wind-blown, and fossils, 20
Satellites, 69, 71
Saurischia, 216–219
Sauropods, 19,* 209, 215, 218–219, 241
Scacchinella, 184
Scale-trees, 35, 39–40, 43,* 170, 183
Scaphites nodosus, 239*
Schizodus harii, 172*
Schmidtella, 53*
Schroederoceras eatoni, 136*
Scorpions, 9, 47, 139, 148, 150,* 157, 171
Scott, D. H., 24
Scott, W. B., 291
Scytalocrinus, 151*
Sea anemones, 48
"Sea scorpions," 148, 150*
Sea squirts, 47
Sea-urchins, 36, 53, 54, 55,* 166,* 167, 238
Seal-trees, 40, 169,* 183
Seaweeds, 37, 39, 131, 133, 135, 137,* 151*
Sedgwick, Adam, 119
Seed-ferns, 35, 37, 41–42, 45, 155, 156,* 183
Seeds, 38, 41–42, 44–45, 174, 237, 273
Selection, artificial, 29, 30
  natural, 29
Sequoias, 43, 206, 264
Series, 11
Serpentine, 78, 99
Sharks, 9, 47, 153,* 168, 246, 265
Shastan sea, 226, 228
Shelf seas, 109,* 231–232, 245
Shell marl, 20
Shields, 74–75, 106, 112
Shore lines, ancient, how determined, 112
Sial, 73
Siberian tundras, 300
Siberian-Alaskan land-bridge, 103, 199, 253, 268,* 274, 280, 284

Sierra Nevada Mts., 122,* 203,* 204, 257, 259
    batholiths in, 200,* 204
Sigillaria, 40, 169,* 183
Silurian, 9, 118, 123, 139–143, 147–148
  economic products of, 142, 144
Silurian, geography of, 108,* 139–143
  life of, 147–149
Silver, 94, 204
Sima, 73
Simpson, G. G., 267, 268
Sinanthropus, 313, 315–317, 322
Siouia, 106, 107*–108,* 117,* 160, 163, 177
Siren lacertina, 188*
Sivapithecus, 312
Slates, black, in Proterozoic, 90
  Ordovician, 129
Smilodon, 290, 291,* 304, 305*
Smith, G. Elliot, 317
Smith, J. P., 184
Smith, William, 7, 24, 199
Snails, 36, 55, 131, 157, 202
  land, first, 171
Snakes, 63
Sodium sulphate, 298
Solar prominences, 70*
  system, origin of, 69
Soleniscus fusiformis, 172*
Solenocheilus kentuckiense, 171*
Sonninia time, 200*
Sonoran plateau, 235
Sonoric geosyncline, see *Ouachitic-Sonoric*
South Africa, glaciation in, 181–182
    Permian reptiles in, 189
South America, 235, 249, 260–261
    glaciation in, 181, 182*
    mammals of, 274, 275*
Sow-bugs, 58
Special creation, theory of, 24
Species, 35
Sphenodon, 64
Sphenophylls, 39
Spiders, 9, 36, 47, 60, 139, 157
Spirifer arenosus, 152*
  cameratus, 172*
  crispus, 149*
  medialis, 152*
  pennatus, 152*
  radiatus, 149*
Spitzbergen, 26, 170
Sponges, 35, 36, 47, 48, 49, 86, 96, 98, 100, 130, 133, 136,* 213
Spongiella, 49*
Spores, 38, 39, 40, 41, 170
Squids, 57, 212
Starfishes, 36, 53, 54, 55*
Staurocephalus murchisoni, 149*
Steeprock limestone, 80, 85
Stegocephalia, 47, 169,* 185, 187, 188*
Stegodon, 283,* 285
Stegomosuchus, 208
Stegomus, 208
Stegosauria, 220–221
Stegosaurus, 220,* 221
Stenotheca rugosa, 132*
Stepheoceras time, 200*
Steropoides diversus, 209*
Strand line, oscillations of, in Pleistocene, 299
Stringocephalus time, 117*
Strongylocentrotus dröbachiensis, 55*
Strophomena planumbona, 136*
Strophostylus cyclostomus, 149*
Struggle for existence, 27–28
Sudbury mining district, 94
Sun, 66, 67–68, 69, 71, 302
Sundance sea, 200,* 201, 202
Supai shale, 158, 177, 178*
    flora of, 183
Superposition, law of, 6
Survival of the fittest, 29
Swamps, coal, 160, 162,* 168, 195
Systems, 11

T

Taconian Disturbance, 9, 129
Tadpoles, 62, 63*
Talchir glacial deposits, 181
Tapirs, 272, 273, 280, 296
Tarsius, 311
Tehuantepec portal, 247,* 249
Teleoceras, 286, 287*
Temiskaming series, 79–80, 81
Tennesseian epoch, 158
Terebratella plicata, 239*
Terebratula harlani, 239*
Termites, 208
Tertiary, 244; see also *Cenozoic*

Tethys, 103, 104,* 184, 213, 243, 261, 263
Tetonius, 312
Tetracorals, 50*
Texas, Permian of, 175–176
Thallophyta, 35, 38–39, 45
Thecosmilia trichotoma, 212*
Theropods, 216–218
Thinopus, 154
  antiquus, 156*
Thousand-legs, 47, 148, 157, 171
Thulean basalts, 261
Tidal theory, of Earth origin, by Jeans, 71
Tillites, 90, 97–98, 262
Tills, 293
Titanotheres, 270,* 275–277
Torosaurus, 222
Trachodon, 220*
Transvaal ice-sheet, 181, 182*
Tree of life, 32,* 35, 36, 37,* 47*
Tree-ferns, 41, 169,* 170, 183
Trees, hardwood, 35, 44, 236
Trematops milleri, 188*
Trenton time, 12, 137
Triarthrus becki, 59*
Triassic, 8, 191–199, 205–213
  climate of, 193, 195, 242
  geography of, 191–199
  life of, 205–213
Triceratops, 221,* 222
Trilobites, 9, 16, 25, 47, 59–60, 100, 130, 131, 132,* 133, 134,* 136,* 137, 138,* 148, 149,* 150, 151, 152,* 168, 172,* 174, 184, 288
Trilophodon, 284
Triplecia extans, 136*
Triticites secalicus, 172*
Trochonema umbilicatum, 136*
Troostocrinus reinwardti, 149*
Tropidoleptus carinatus, 152*
Tropigastrites rothpletzi, 211*
Tropites subbullatus, 211*
Tully paleogeography, 117*
Tundras, 20, 299–300
Tunicates, 36
Turritella mortoni, 22*
  whitei, 239*
Turtles, 63, 202, 208
Tyrannosaurus rex, 217, 218,* 241, 288
Tyrolian time, 8, 191; see also *Triassic*

U

Uddenites time, 175*
Uinta basin, 253, 254*
Ullmannia, 183
Unconformability, law of, 6
Unconformities, 6
Uniformitarianism, 7, 102
Universe, 66, 68
Unkar series, 89, 91, 178*
Uplift, Cenozoic, 255, 261
  Triassic, 193
Upper Cretaceous, 8, 229–233, 236–243
    climate of, 262
    geography of, 104,* 229–233
    life of, 236–243
Uptonia time, 200*
Urochordata, 61
Ursus, 35
  spelœus, 289

V

Variation, 28–29
Varves, 294
Ventura Co., Calif., Cenozoic of, 252, 253
"Vermilion Cliff" sandstone, 202
Vermilion formation, 86
Vero, Florida, man, 321
Vertebrates, 31, 35, 36, 47, 61–65; see also *Fishes*, etc.
  defined, 46
  number of kinds of, 34
Vinci, Leonardo da, 24
Vishnu series, 80, 91, 93,* 178*
Volcanic ash, 13, 127, 255
    and fossils, 20
  waters, 72, 73
Volcanoes and volcanism, 20, 73, 78, 89, 94
    Cenozoic, 247, 249, 250, 252, 253, 255, 259, 260
    Cretaceous, 228, 231, 235
    Devonian, 117,* 146
    Jurassic, 200,* 201, 204
    Ordovician, 127
    Pennsylvanian-Permian, 163
    Pleistocene, 260, 303
    Silurian, 139, 142
    submarine, 198, 201
    Triassic, 192,* 193, 197, 198
Voltzia, 183

W

Waagenoceras cumminsi, 171*
Walchia, 183
Walcott, Charles D., 130, 133
Waptia fieldensis, 134*
Warping, Pleistocene, 292, 298, 299
Warren, P. S., 126
Wasatch basin, 253, 254*
  Mts., 122,* 258*
  time, 272
Wasps, 208
Waverlian epoch, 158
Waynesville paleogeography, 128*
Weasels, 274, 289
Wegener theory, 4, 102
Whales, 265, 271, 299
"White Cliff" formation, 202
White Mts., 146
Whitewater series, 90
Whitfieldella nitida, 149*
Wielandiella, 237*
Williams, H. S., 160
Wind River basin, 253, 254*
  time, 272
Windsor Disturbance, 160, 161
  formation, 158
Wisconsin glaciation, 296, 313
Wolves, 36
Woodward, A. S., 317
Word paleogeography, 175*
Worms, 36, 47, 51, 100, 133, 134*
  segmented, see *Annelids*
Worthenia tabulata, 172*

Y

Yard, R. S., 202
Yellowstone Park, 20, 36, 264
Yohoia plena, 134*
  tenuis, 134*
Yukonia, 107,* 108,* 109*

Z

Zalambdalestes, 269*
Zaphrentis umbonata, 50*
Zeuglodonts, 265
Zion Canyon, Utah, 202
Zittelella typicalis, 136*

DATE DUE

OCT 27 '93			
MAR 02 '94			

Demco, Inc. 38-293

CINCINNATI BIBLE COLLEGE & SEM. LIBRARY
560.9 S384o main
Schuchert, Charles/Outlines of historica
3 4320 00054 2557

560.9 S384o

Schuchert, Charles.

Outlines of historical geology

CT 27 '93

MAR 02

101135AJP
98000

GEORGE MARK ELLIOTT LIBRARY
The Cincinnati Bible Seminary

560.9 S384o

Schuchert, Charles.

Outlines of historical geology

DEMCO